SYSTEM-WIDE SIGNIFICANCE OF PREDATION ON JUVENILE SALMONIDS IN COLUMBIA AND SNAKE RIVER RESERVOIRS

Annual Report 1990

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ABSTRACT

The consumption rates of northern squawfish (<u>Ptychocheilus oresonensis</u>) preying upon juvenile salmonids were indexed in four reservoirs (Bonneville, The Dalles, John Day and McNary) of the lower Columbia River. During the spring and summer of 1990, over 2,000 northern squawfish were collected from dam forebays, dam tailraces and mid-reservoir locations. Gut content data, predator weight and water temperature were used to compute a consumption index (CI) for northern squawfish. Stomach contents of smallmouth bass (<u>Micronterus dolomieui</u>), walleye (<u>Stizostedioq vitreum</u>), and channel catfish (<u>Ictalurus punctatus</u>) were also collected.

Juvenile salmonids were found in 435 of 1,598 northern squawfish guts analyzed. Besides salmonids and other preyfish, crustaceans formed a significant portion of the diet. Mollusks, insects and plant material were also observed in the diet at certain locations.

The CI of northern squawfish varied by season and location. At most locations, summer CI's of northern squawfish were higher than in the spring. The highest CI's were observed during summer in the tailraces of McNary (7.5) John Day (4.0) and Bonneville Dams (3.9). Northern squawfish collected in forebays had intermediate CI's while fish collected in mid-reservoir locations had the lowest CI's. Northern squawfish from the boat restricted zones within tailrace and forebay locations had the highest CI's (maximum 11.2). Reservoir-wide northern squawfish CI's (excluding boat restricted zones) ranged from near zero (Bonneville and The Dalles) to 0.6 in John Day reservoir during the spring; the CI range in the summer was zero to 0.2. Efforts to match sample collection with times of highest juvenile salmonid passage were successful except during July at The Dalles and Bonneville Reservoirs. Consumption indices were moderate to high at several locations even when passage was relatively low, suggesting salmonid predation rate by northern squawfish was not always a function of prey density. Future work will integrate

consumption index results with predator abundance data (ODFW) to allow a ranking of sampled areas according to estimated loss of juvenile salmonids to northern squawfish.

ACKNOWLEDGEMENTS

INTRODUCTION

The U.S. Fish and Wildlife Service (FWS) and the Oregon Department of Fish and Wildlife (ODFW) recently completed a six year study to determine the significance of predation on juvenile salmonids in John Day Reservoir (Poe and Rieman 1988). Study results provided estimates of juvenile salmonid losses to predators which indicated that predation may account for the majority of previously unexplained losses of juvenile salmonids in John Day Reservoir (Rieman et al. 1988). Continuing need for predation research has been designated as high priority by several regional committees and agencies including: (1) the Northwest Power Planning Council ((section 403(d) (1)) of the 1987 Columbia River Basin Fish and Wildlife Program): (2) the Water Budget Evaluation - Reservoir Mortality Technical Work Group (TWG minutes of January 27, 1989 meeting); and (3) the 1989 Predator-Prey Modeling Workshop (Fickeisen et al. 1990).

Although predation was significant in John Day Reservoir, we don't know if predation is a significant mortality factor in other Columbia River reservoirs. Because predation management is an ongoing program (Nigro et al. 1990) we also need to: (1) establish baseline data on predator abundance and consumption rates in other reservoirs to evaluate the effectiveness of predation management actions: (2) determine where predation management actions should be implemented: and (3) further develop predation models to help evaluate predation management and to predict cumulative impacts of predators on juvenile salmonid survival throughout the system.

In 1989 a collaborative study of the FWS and ODFW was initiated to develop a predation index to estimate the relative magnitude of juvenile salmonid losses to predators in reservoirs throughout the Columbia River Basin. Development of the index was completed in 1990 and detailed descriptions of the analytical, field, and laboratory techniques for a consumption rate index for northern squawfish (Ptychocheilus oreaonensis) may be found in Petersen et al. (1990); corresponding methods for

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abundance indexing may be found in Vigg and Burley (1990a).

This report presents the results of indexing northern squawfish consumption rates upon juvenile salmonids during their 1990 out-migration through four reservoirs in the lower Columbia River.

METHODS

Field Methods

Field sampling for 1990 was completed at 14 locations from Bonneville Dam tailrace through the upper reaches of McNary reservoir and Ice Harbor Dam tailrace in the Snake River (Figure 1 and Table 1). For each reservoir, sample "locations" were selected that represented a forebay, mid-reservoir and tailrace area (Figure 2). Within each location, 24 transects were established, each transect being approximately 500 m. At forebays and tailraces of each dam, 4 of the 24 transects were within the boat restricted zone (BRZ) and 20 were outside the BRZ - 10 being on each side of the river for an approximate distance of 6 km. To facilitate interpretation of results, the position of transects in each dam tailrace and forebay BRZ is shown in Figure 3.

Dam, or project, operations were adjusted to allow sampling within the BRZ and around ice trash sluiceways, spillgates, and powerhouse outflows. Sampling occurred immediately after any project operation change, so gut contents of captured predators should be reflective of typical operating conditions.

A minimum target catch of 30 northern squawfish per day at each location was established (see Petersen et al. 1990); however, around dams the minimum target catch was broken into two units: 15 per day in the BRZ and 15 per day outside the BRZ. Sampling was initiated 90 minutes before sunrise at all locations. The target predator was northern squawfish; smallmouth bass (<u>Micropterus dolomieui</u>), walleye (<u>Stizostedion vitreum</u>), and channel catfish (<u>Ictalurus ounctatus</u>) were also

Table 1.   Sampling locations and dates for northern squawfish Consumption Indexing, 1990.   Tr=Tailrace, Fb=Forebay, Mr=Mid-reservoir, and Up=Upper reservoir.

RESERVOIR Location		RIVER KILOMETER	SPRING	SUMMER
Bonneville	Tr	225-233	5/11-5/23	7/23-7/25
BONNEVILLE				
Bonneville	Fb	233-239	5/21-5/23	7/23-7/25
Bonneville	Mr	273-285	5/16-5/18	7/17-7/18
The Dalles	Tr	301-307	5/14-5/15	7/16-7/17
THE DALLES				
The Dalles	Fb	307-315	5/15-5/16	7/9-7/10
The Dalles	Mr	329-333	5/17-5/18	7/11-7/12
John Day	Tr	340-347	5/9-5/10	7/2-7/3
JOHN DAY				
John Day	Fb	347-353	5/7-5/9	7/2-7/3
John Day	Mr	387-395	5/9-5/10	6/25-6/26
McNary	Tr	459-468	5/7-5/8	6/25-6/26
MCNARY				
McNary	Fb	468-474	5/2-5/3	6/20-6/21 7/6
McNary	Mr	497-504	4/30-5/1	6/18-6/19
McNary	UP	537-544	5/2-5/3	6/20-6/21
Ice Harbor	Tr'	10-16	4/30-5/1	6/18-6/19 7/6

1 Snake River
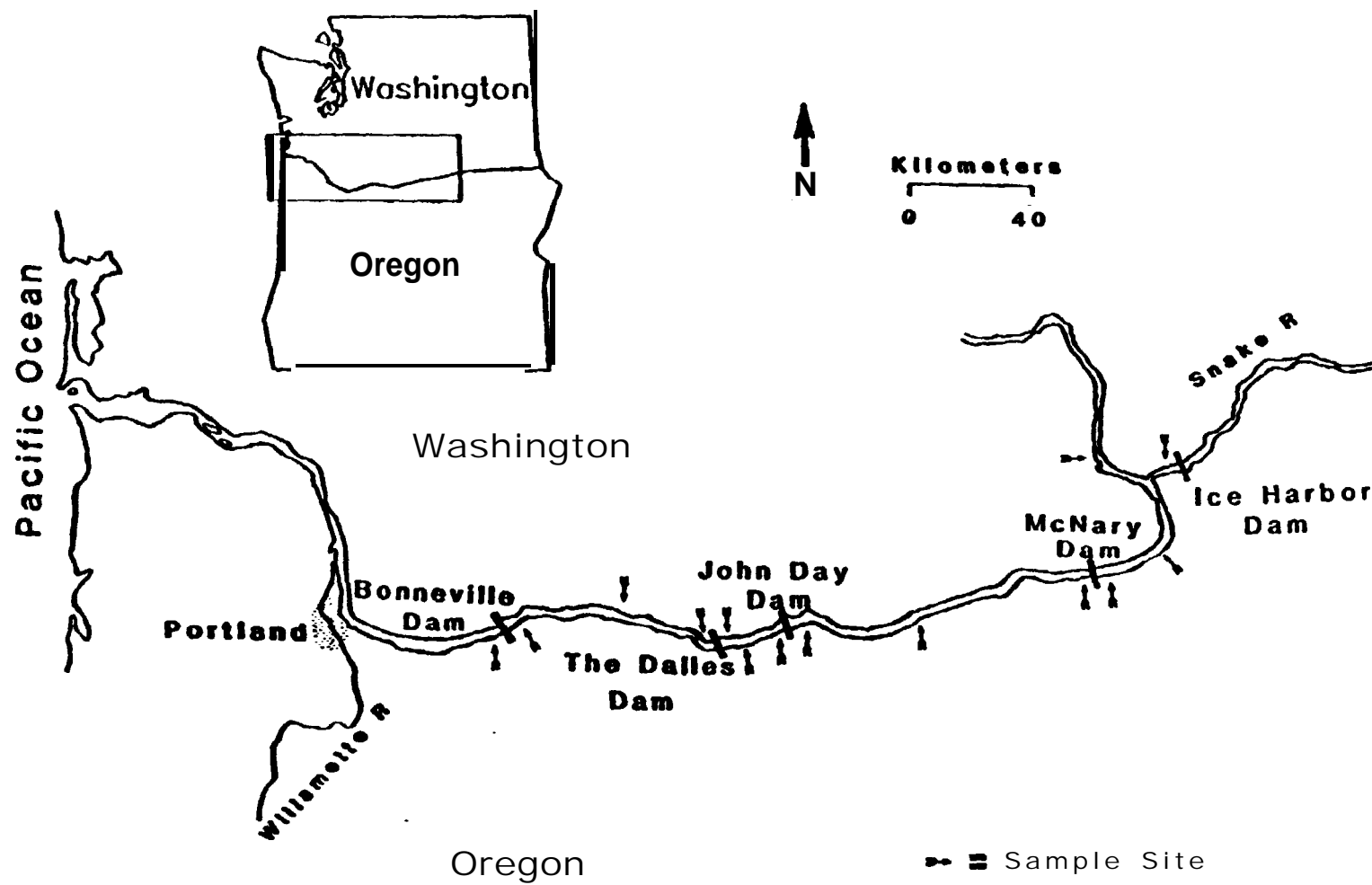
Figure 1. Sampling locations (arrows) for Consumption Indexing during 1990.
See Table 1 for specific location information.

Text Descriptor	Sample Pooling Pattern					Text Table #	
						CI	Diet
	Forebay	Mid-Reservoir		Tailrace			
Locations		No Samples	No Samples			3	7&8
Reservoir-wide		No Samples	No Samples			6	11&12
BRZ only		No Samples	No Samples			4	9&10

Figure 2. Sample pooling patterns for northern squawfish consumption index (CI) and diet analyses. Each horizontal diagram represents a simple reservoir, bounded by two dams, in the lower Columbia River. For a particular analysis, data were pooled from areas of the reservoir having the same fill-pattern in the diagram. Diagrams are not to scale.

Bonneville Darn

Flow

The **Dalles Dam**

Flow
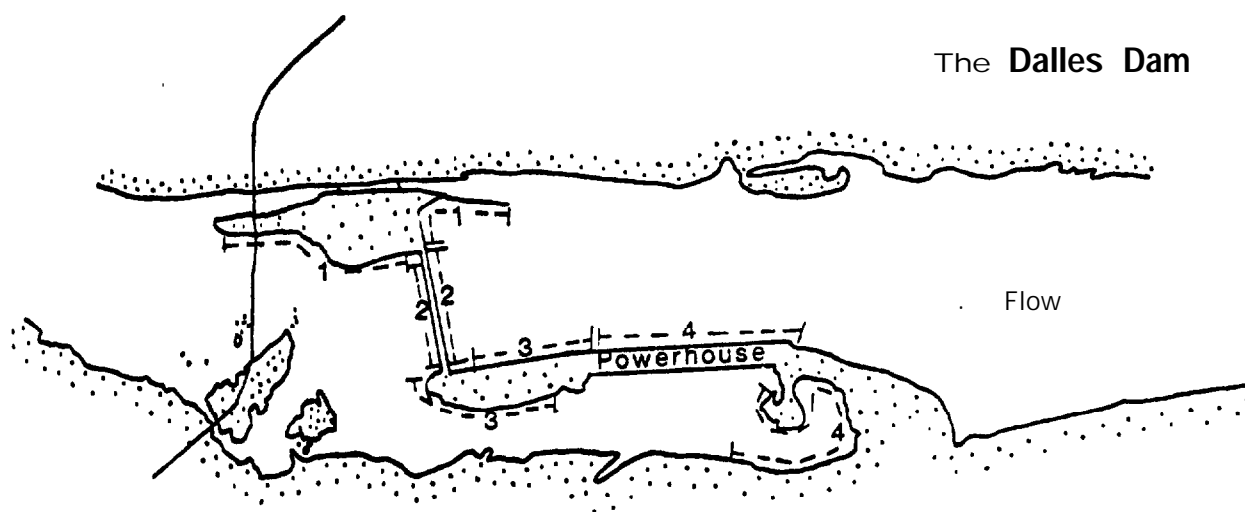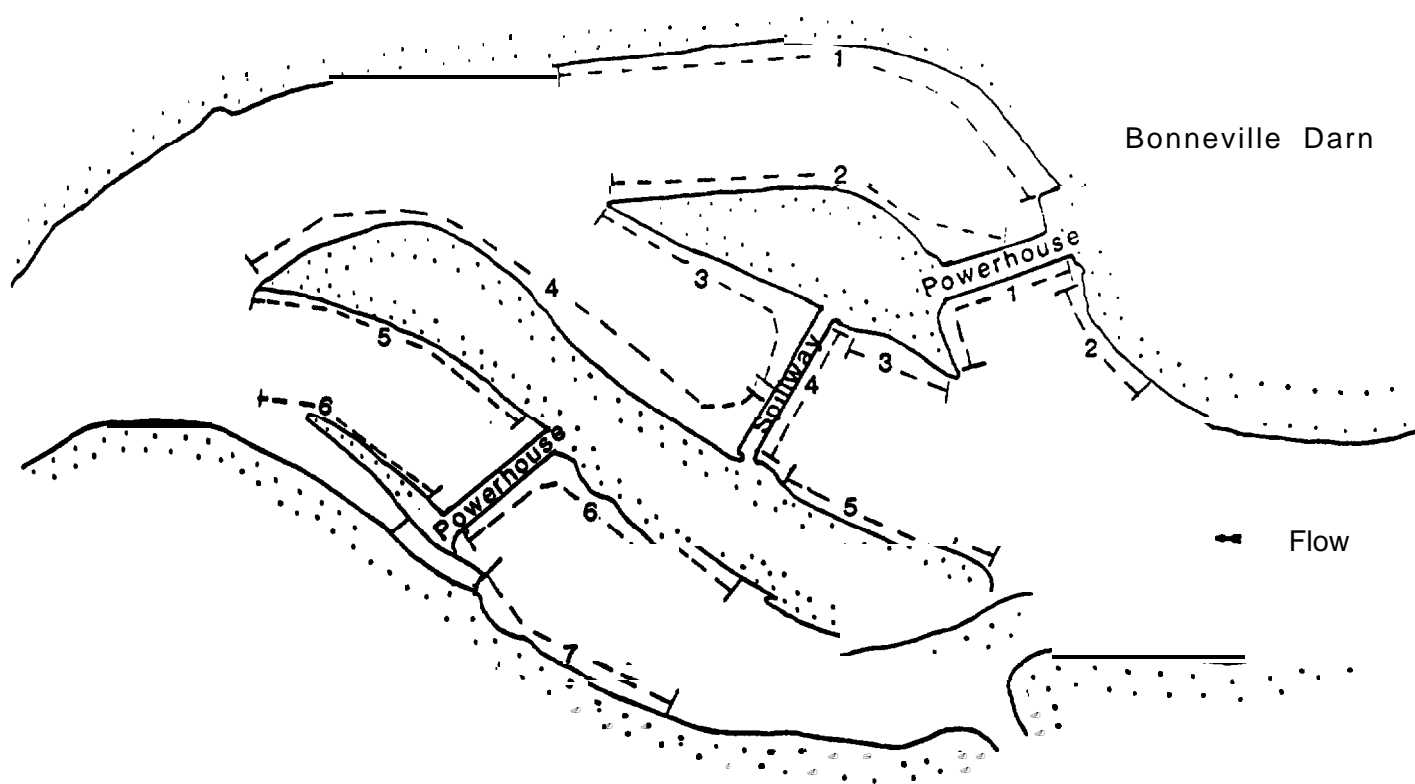
Figure 3. Location of 1990 sampling transects in the Boat Restricted Zones **(BRZ)** of each dam tailrace and forebay. Upriver is on the right in all drawings.

McNary Dam

— Flow

Ice Harbor Dam

Flow

John Day Dam

Flow
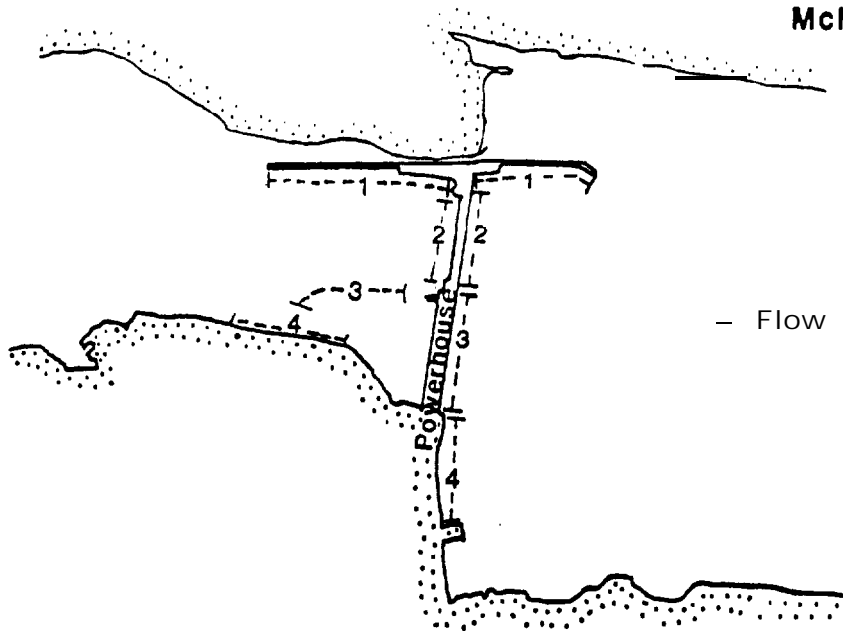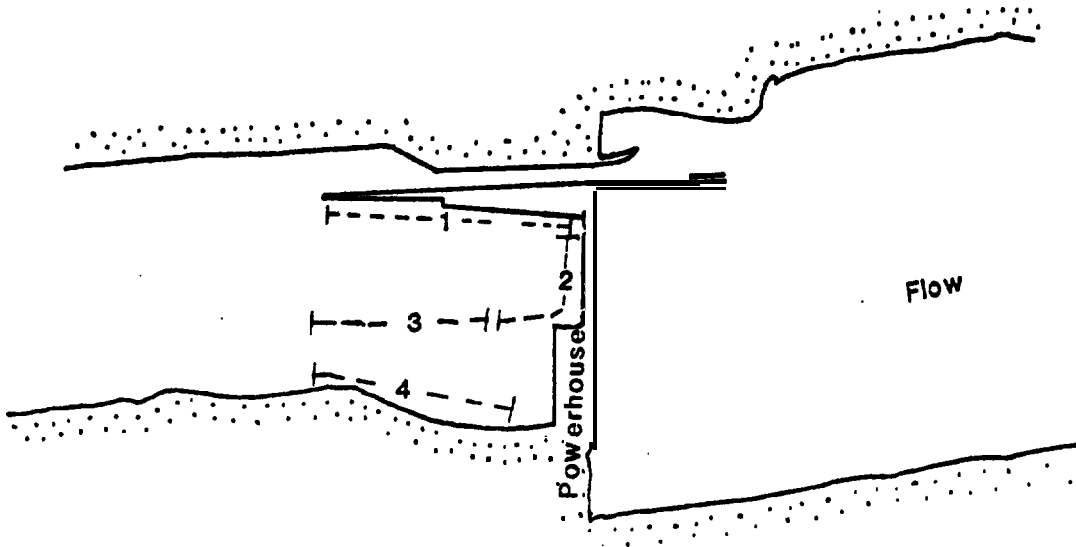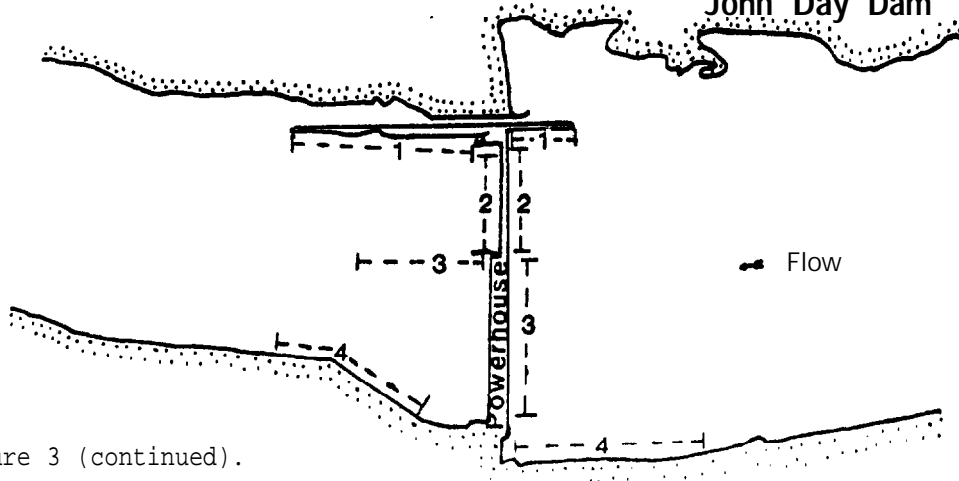
Figure 3 (continued).

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collected for gut sampling.

Two 18-ft Smith-Root' electrofishing boats were used to capture predators, which were retained alive in circulating live wells until processing of gut contents. Transects were electrofished for 15 minute intervals with the first six transects chosen randomly; additional, discretionary transects were fished to maximize catch of northern squawfish. Electroshocking was briefly stopped during sampling to allow in situ recovery of adult salmonids and white sturgeon, which had been incidentally shocked.

Northern squawfish were given a lethal dose of MS 222; data were collected on fork length (FL, nearest mm), weight (nearest 5 or 10 g, depending upon fish size), sex, and state of maturity. Scales, otoliths, and opercles were removed for age and growth information. Gut contents of northern squawfish over 250 mm FL were taken using techniques described in Petersen et al. (1990). Walleye, smallmouth bass, and channel catfish 2 200 mm were anesthetized using MS 222; fork length, weight and scales (pectoral spines of channel catfish) were taken and stomachs were pumped with a modified Seaburg stomach sampler (Seaburg 1957). All gut or stomach contents were placed in plastic bags and kept on ice until freezing; samples were kept frozen until laboratory analysis.

Laboratory Methods

In the laboratory, gut samples were thawed and removed from the sample bags. Intestinal parasites, fat, and other material not ingested were discarded. Gut contents were examined with a magnifying lamp and divided into major prey taxa groups (i.e., fish, crustacean, mollusks, insects, plant and other). Each prey group was blotted by placing the sample on tissue paper for 30 s, weighed to the nearest 0.01 g and returned to the sample bag.

In order to speed laboratory processing of gut contents, a

'Mention of brand names does not constitute endorsement by the U. S. Government.

digestive enzyme technique was used (Petersen et al. 1990). The
enzyme solution was prepared using lukewarm tapwater, 2% (by
weight) strength pancreatin (8x porcine digestive enzyme) and 1%
 (by weight) sodium sulfide. The solution was poured into sample
bags until contents were submersed. Contents were briefly
stirred to ensure all surface areas were in contact with the
digestive enzyme. Samples were then placed in a desiccating oven
at **40°C** for 24 hr. After all flesh was digested, the contents
were rinsed through a 425 micron (#40) sieve with tap water. A
dissecting microscope and forceps were used to remove
diagnostic bones (primarily cleithra, dentaries, and opercles)
from the samples.   Diagnostic bones were identified (salmonid,
sculpin, or other preyfish), paired to enumerate prey fish
consumed, and preserved in labeled vials with 95% ethanol.
        Field and laboratory data were stored in a relational
database, which is described in Appendix A.

Consumption Index
        Detailed methods and index derivation for the northern
squawfish CI were presented in Petersen et al. (1990); an
abbreviated description of the CI is presented here for
completeness.
        The estimated number of salmonids consumed per day by an
individual predator, p, can be expressed as:

$$C_p = \sum_{i=1}^{n} 1 / (\text{Evacuation time for prey item } i)$$

or,

$$C_p = \sum_{i=1}^{n} 1 / D90_i \tag{1}$$

where C_p is consumption rate (number of salmonids . individual
northern **squawfish**$^{-1}$. day-'), $D90_i$ is number of days to 90%
digestion for salmonid prey item i, and n is total number of
salmonids found in the gut. Using 90% digestion time, rather
than l00%, avoids the problem of non-digestible prey parts that

may remain in the gut for extended periods. Equation (1) is equivalent to:

$$C_p = \sum_{i=1}^{n} (24 / T90_i) \qquad (2)$$

where T90, is number of hours to 90% digestion for the ith salmonid prey **item.** T90, was calculated by Beyer et al. (1988) and modified by Rieman et al. (1988) to:

$$T90_i = 1147 * M_i^{0.61} * T^{-1.60} * W_p^{-0.27} \qquad (3)$$

where M_i is meal size (g) at time of ingestion of salmonid prey item i, T is water temperature (°C), and W_p is predator weight (g). Substituting equation 3 into 2 and rearranging gives:

$$C_p = 0.0209 * T^{1.60} * W_p^{0.27} * \sum_{i=1}^{n} M_i^{-0.61} \qquad (4).$$

Equation 4 provides an estimate of daily salmonid consumption per northern squawfish, but still requires estimation of meal size (M,) through intensive gut analysis and complicated data analysis. The following formula was chosen as a CI, based upon simplicity of data required and percent variance explained:

$$CI = 0.0209 * T^{1.60} * MW^{0.27} * [MTsal * MGutwgt^{-0.61}] \qquad (5)$$

where T is water temperature, MW is mean predator weight (g), MTsal is mean number of salmonids per predator, and MGutwgt is mean gut weight (g) per predator. All variables in CI are averaged over all predators in a sample: CI is the consumption index for a collection (sample) of predators.

The CI for northern squawfish, as derived above, isnot meant to be a rigorous method for estimating the number of juvenile salmonids eaten per day by an average predator. The CI is based upon the simple idea of meal turnover times and does not consider such aspects of consumption as diel feeding pattern and

evacuation rate of prey. In an analysis of data from John Day
Reservoir (Petersen et al. 1990), the consumption rate of
northern squawfish (CR - juvenile **salmonids·predator^{-1}·day^{-1}**) was
related to CI by:

$$\log_{10}(\text{CR}) = 1.17 * \log_{10}(\text{CI}) - 0.41 \qquad N = 86 \qquad r^2 = 0.89 \ .$$

   Distribution characteristics of the northern squawfish CI
were computed by a bootstrap resampling technique (Efron and
Tibshirani 1986; Petersen et al. 1990). For each sample of N
predators, a computer program randomly selected N individual
predator records and calculated a new CI. Five hundred CI's were
computed for each CI distribution; preliminary studies showed
that variances and confidence bounds were stable with 500
samples. The number of predators per bootstrap sample was set to
the original sample size (N), or 60 if N was greater than 60.
   Consumption Index (CI) and diet summary analyses for
northern squawfish were done by pooling sample data in three
different patterns (Figure 2). The rationale for the "reservoir-
wide" and "BRZ only" analyses (Figure 2) is within the Results
section.

Bioenergetics Index
   A bioenergetics index (BI) of northern squawfish consumption
rate, which would complement the direct CI, has been under
development and testing (Petersen et al. 1990). The BI uses a
general bioenergetics model of fish growth (Hewett and Johnson,
1987, 1989), parameterized to northern squawfish, to estimate
consumption rate for a time period. The BI has not yet been
calculated for northern squawfish in the mainstem Columbia River
reservoirs because we have not completed ageing subsamples of the
predators from each reservoir; ageing work is currently
underway. Two aspects of bioenergetic modeling of northern
squawfish will be reported here: 1) Age determination methods,
and, 2) parameter refinement for the model.
   Scales were collected from all northern squawfish ≥ 250 mm

FL caught during 1990. Approximately 15-30 scales were collected from the area below the posterior base of the dorsal fin and above the lateral line. Scales were prepared for mounting by placing them into a petri dish containing warm water and cleaned with a fine brush. Approximately 4-6 non-regenerate scales per fish were selected, placed on labeled gum cards and heat pressed onto acetate. Scale impressions were projected using a microfiche projector at 42x. Scales were read and ages assigned according to the methods outlined by Bagenal and Tesche (1978) and Jearld (1983). Location of annuli and scale edge were marked on strips of paper to provide a permanent record of the scale reading. Two scales per fish were read by two independent readers. In the event that a reader could not assign the same age to two scales from the same fish, or the two readers assigned different ages to a fish, both readers would collectively age that fish and resolve any discrepancies. Scale ageing techniques were coordinated with ODFW.

In addition to determining ages with scales, opercles and otoliths were collected and used to compare ages assigned to individuals by scale readings. Collection, preparation, and reading of opercles followed methods given by McConnell (1951) and Scoppettone (1988). Otoliths were mounted on glass slides with hot glue and ground to the focus with fine grit emery paper. As in the case with scales, ages were determined by two independent readers and differences were resolved collectively.

Previous studies with the northern squawfish bioenergetics model showed a high sensitivity in model output (accumulated juvenile salmonid consumption in g) to respiration parameters (Petersen et al. 1990). Respiration parameters specific to northern squawfish were not available for the initial model implementation, so parameter values from related species or "generic" values were used (Hewett and Johnson 1987, e.g.).

Because of the high model sensitivity and lack of species-specific respiration parameters, we considered research on northern squawfish respiration rates important. A collaborative study with Joseph Cech, Jr. (University of California, Davis) on

the effects of temperature and fish size upon basal respiration rate was conducted during July, 1990. Data from this study will be used to refine respiration parameters in the northern squawfish bioenergetics model. Results of the respiration study will be submitted to a peer-reviewed journal; a draft report of study results is included as Appendix B.

RESULTS

Catch Summary

In the 1990 consumption index field sampling season a total of 2367 predators were captured. Northern squawfish accounted for 85% (2017) of the catch of the four target predators. Other predators collected were smallmouth bass (13%, n=310), walleye (1%, n=26) and channel catfish (<1%, n=14) (Table 2).

Of the 2017 squawfish captured 40% were collected from the Bonneville Dam tailrace and forebay. The numbers of northern squawfish captured per reservoir generally decreased from Bonneville Reservoir up-river. Northern squawfish fork lengths ranged from 154-481 mm (mean=336 mm, n=551) for males and 231-570 mm (mean=412 mm, n=1413) for females: weights ranged from 40-1420 g (mean=478 g, n=551) for males and 130-2450 g (mean=949 g, n=1411) for females.

Sex ratio of the northern squawfish catch was 70% females, 27% males, and 3% undetermined. Catches of females were generally higher near the dams than at mid-reservoir locations, except for Ice Harbor Dam tailrace BRZ (summer) where males made up 58% of the catch. Ninety-nine percent of the northern squawfish collected in the spring had developing gonads. During summer, 48% of the females had developing gonads, 16% were ripe and 32% were spent. Of males collected during the summer, 10% had developing gonads, 75% were ripe and 12% were spent.

Smallmouth bass were collected in all of the reservoirs and the Bonneville Dam tailrace (Figure 4); however, smallmouth bass were not found in abundance within the BRZ's of the dams. Up-river from Bonneville Dam, the proportion of smallmouth bass in

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Table 2. Number of predators collected during northern squawfish CI sampling, 1990. N=Number, M=Male, F=Female, U=Unidentified sex, SMB=Smallmouthbass, WAL=Walleye, CHC=Channelcatfish, Tr=Tailrace, Fb=Forebay, Mr=Mid-reservoir, and Up=Upper reservoir.

RESERVOIR Location	NORTHERN SQUAWFISH				SMB	WAL	CHC
	N	M	F	U			
SPRING							
Bonneville Tr	204	57	132	15	6	5	0
BONNEVILLE							
Bonneville Fb	195	31	163	1	0	0	0
Bonneville Mr	40	17	21	2	0	0	0
The Dalles Tr	48	9	39	0	10	0	0
THE DALLES							
The Dalles Fb	38	1	37	0	0	0	0
The Dalles Mr	15	4	11	0	7	1	0
John Day Tr	100	35	65	0	11	7	0
JOHN DAY							
John Day Fb	38	10	28	0	9	0	0
John Day Mr	6	4	2	0	17	0	0
McNary Tr	84	16	67	1	0	0	0
MCNARY							
McNary Fb	24	1	23	0	11	0	0
McNary Mr	9	0	9	0	5	0	0
McNary UP	33	4	29	0	13	1	0
Ice Harbor Tr	14	4	10	0	3	0	4
SPRING TOTAL	848	193	636	19	92	14	4
SUMMER							
Bonneville Tr	236	102	124	10	2	0	0
BONNEVILLE							
Bonneville Fb	173	25	132	13	3	0	0
Bonneville Mr	49	19	30	0	6	1	0
The Dalles Tr	70	17	51	2	4	0	0
THE DALLES							
The Dalles Fb	61	11	50	0	8	0	0
The Dalles Mr	56	18	31	7	15	1	0
John Day Tr	144	25	118	1	8	2	0
JOHN DAY							
John Day Fb	16	11	5	0	12	0	0
John Day Mr	7	1	5	1	16	0	0
McNary Tr	150	35	115	0	10	8	1
MCNARY							
McNary Fb	9	1	8	0	32	0	0
McNary Mr	14	1	13	0	4	0	0
McNary UP	36	12	24	0	79	0	0
Ice Harbor Tr	149	80	68	0	20	0	8
SUMMER TOTAL	1169	358	777	34	219	12	9
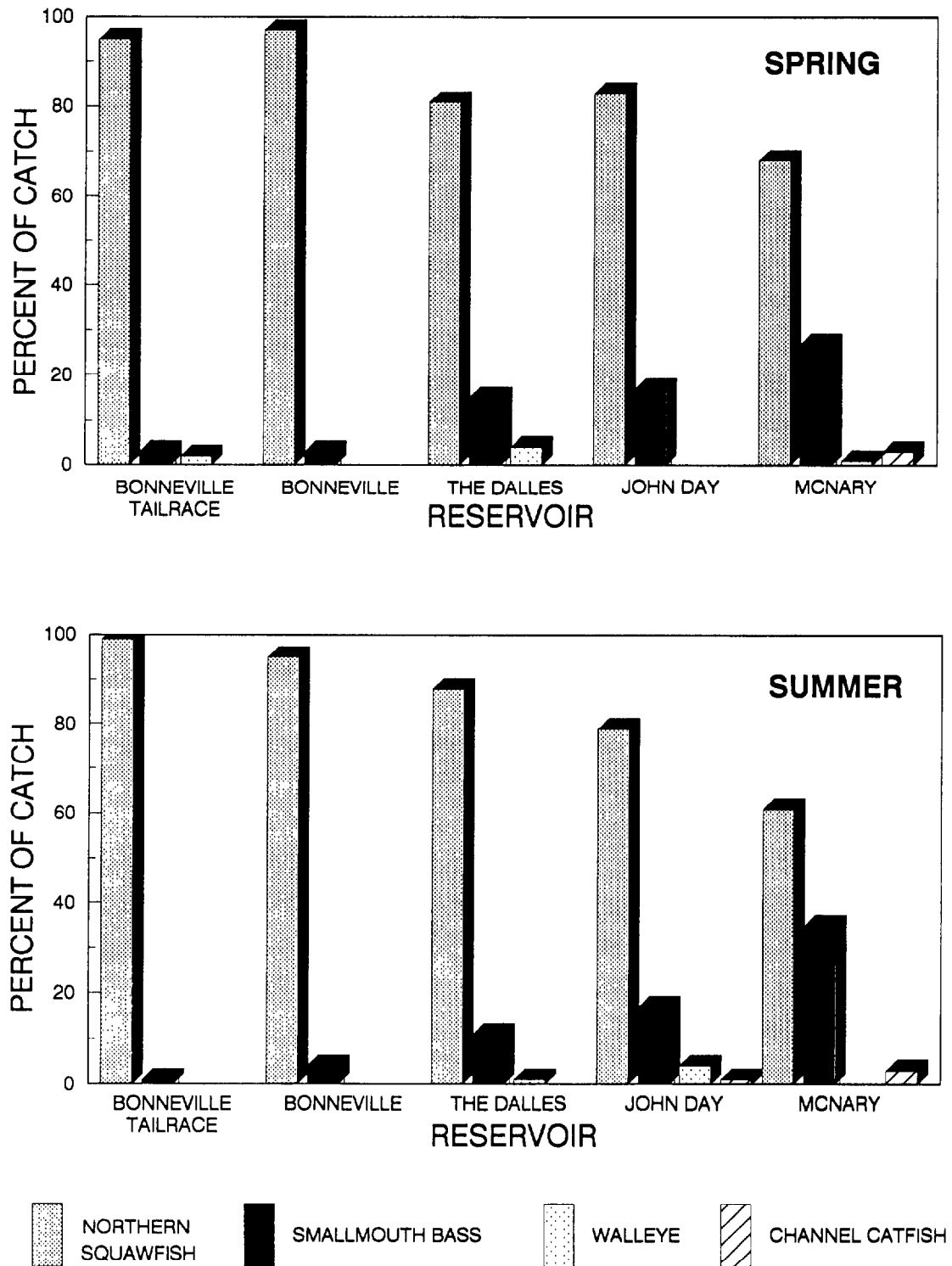
Figure 4. Percent of the predator catch per reservoir during 1990 spring and summer Consumption Indexing. Reservoirs represented are from dam to dam, including the BRZs. Bonneville Dam tailrace is included but is not considered a reservoir.

the total catch increased (Figure 4). Of the 310 smallmouth bass
collected, 30% were captured at the upper McNary location, 14% in
the McNary Dam forebay and 11% at the John Day mid-reservoir
location.

Walleyes were captured throughout the sampled reservoirs in
low numbers. Most common occurrences were associated with dam
tailraces but some fish were taken in mid-reservoir locations.
No walleyes were taken in a dam forebay area.

Channel catfish were collected in low numbers (Figure 4). A
total of 14 fish were collected during the entire sample season,
13 from Ice Harbor Dam tailrace.

Suckers (Catostomus ssp., primarily large-scale, **C.**
macrocheilus,and bridgelip suckers, **C.** columbianus) were the
most common non-target fish observed while electrofishing. Other
species commonly observed during sampling included: carp
(Cyprinus carpio), peamouth (Mylocheilus caurinus), chiselmouth
(Acrocheilusalutaceus), and American shad (Alosa sanidissima).
The highest diversity **of** species occurred at the upper McNary
location where a total of 13 non-target species were identified
in addition to target predators captured.

Adult salmon, steelhead and white sturgeon were
occassionally shocked during sampling. The sampling crew stopped
electroshocking to allow these fish to recover or drift out of
the current field. Incidentally shocked adult salmonids and
white sturgeon were not netted or followed downriver, so no
estimate of their mortality was possible.

Consumption Indexing
Analyses of the variability of northern squawfish data
collected during 1983-86 in John Day Reservoir suggested that 15-
30 fish per day, or **30-60** fish per two-day period, would provide
a reasonable sample for indexing consumption (Petersen et al.
1990). During 1990 sampling, we caught the minimum of **30** fish,
during two days of effort, at 9 of 14 locations in the spring and
10 of 14 locations in the summer (Table 3). The 2-day upper
target of 60 fish proved more difficult and was achieved on 10 of

Table 3. Northern squawfish consumption indices (CI) at locations in the lower Columbia and Snake Rivers during 1990. Note that a single 0 means no juvenile salmonids were found in the predator guts while 0.0 means the estimate was less than 0.05. CI is the consumption index for the original sample (N). Mean CI, standard deviation (SD), coefficient of variation (CV, %) and quartiles are given for the 500 bootstrap samples. Tr=Tailrace, Fb=Forebay, Mr=mid-reservoir, Up=Upper reservoir.

RESERVOIR Location		N	CI	Bootstrap Summary			Quartiles	
				Mean	SD	CV	25th	75th
SPRING								
Bonneville	Tr	149	2.2	2.2	0.4	17	2.0	2.5
BONNEVILLE								
Bonneville	Fb	153	0.6	0.6	0.2	32	0.5	0.7
Bonneville	Mr	39	0	0	0		0	0
The Dalles	Tr	48	1.5	1.6	0.4	22	1.4	1.8
THE DALLES								
The Dalles	Fb	38	0.8	0.8	0.2	28	0.7	0.9
The Dalles	Mr	15	0	0	0		0	0
John Day	Tr	77	0.9	0.9	0.1	15	0.8	0.9
JOHN DAY								
John Day	Fb	38	1.5	1.5	0.2	13	1.4	1.6
John Day	Mr	6	0	0	0		0	0
McNary	Tr	77	2.2	2.2	0.2	10	2.1	2.4
MCNARY								
McNary	Fb	24	1.4	1.4	0.3	22	1.2	1.6
McNary	Mr	9	0.2	0.1	0.1	75	0.0	0.2
McNary	UP	33	1.5	1.7	0.7	44	1.2	2.1
Ice Harbor	Tr	14	4.8	5.5	4.2	77	2.4	7.1
SUMMER								
Bonneville	Tr	154	3.9	3.8	1.0	25	3.1	4.5
BONNEVILLE								
Bonneville	Fb	139	1.6	1.6	0.6	36	1.2	2.0
Bonneville	Mr	42	0	0	0		0	0
The Dalles	Tr	67	0.4	0.4	0.2	48	0.0	0.6
THE DALLES								
The Dalles	Fb	61	0.9	0.9	0.5	51	0.6	1.2
The Dalles	Mr	51	0.1	0.1	0.1	98	0.0	0.2
John Day	Tr	96	4.0	4.0	0.7	18	3.5	4.5
JOHN DAY								
John Day	Fb	16	2.2	2.5	1.8	74	1.1	3.4
John Day	Mr	7	0.9	1.1	1.1	106	0.0	1.5
McNary	Tr	75	7.5	7.5	1.3	17	6.7	8.4
MCNARY								
McNary	Fb	9	2.3	2.4	1.2	50	1.6	3.3
McNary	Mr	13	1.6	1.7	1.0	59	0.9	2.3
McNary	UP	36	1.5	1.5	0.5	34	1.1	1.8'
Ice Harbor	Tr	112	0.5	0.6	0.3	62	0.3	0.7

28 time-locations (Table 3).

Difficulty in meeting sampling targets at specific locations, especially mid-reservoir locations (Table 3), reduced the statistical power with which comparisons could be made since small-sample variation tended to be greater than variation in samples with many northern squawfish; for example, coefficients of variation were inversely related to sample size, in general (Table 3). To estimate the statistical power (1.0 minus Type II error; Type I error set to .05) achievable when comparing **CI's,** we calculated the power for some hypothetical comparisons and averaged similar power estimates. **CI's** from mid-reservoir locations, which had the smallest samples and the greatest variability, were examined as a conservative example. Measured **CI's** from mid-reservoir locations (N=6) were compared to a hypothetical CI that was one-half the measured estimate (CI vs. **CI/2;** average power = 89%), and also to a hypothetical CI that was two times the measured CI (CI vs. **2*CI;** average power = 97%). Comparisons of **CI's** from tailrace and forebay locations had even higher power because the measured CI estimates from these locations had smaller relative standard deviations **(CV's;** Table 3) than the **CI's** from the mid-reservoir locations. These results indicate that locations can be ranked, with high confidence (power) , by their relative consumption rates.

Consumption indices of northern squawfish ranged from zero at several locations to 7.5 in the McNary tailrace during summer sampling (Table 3). Northern squawfish collected from tailraces and forebays tended to have the highest CI values with a few exceptions. Mean **CI's** were always very close to the CI based upon the original fish sample, as expected. The coefficient of variation of northern squawfish CI means averaged 43%, with a high value of 106% in John Day mid-reservoir when sample size was only 7 northern squawfish (Table 3).

Compared to the spring period, northern squawfish CI's were higher during the summer in 10 of the 14 locations (Table 3). For these 10 locations, index values increased from spring to summer by an average of 1.5 CI units. The only notable

exceptions to higher summer consumption at a location occurred in The Dalles tailrace and Ice Harbor tailrace, which both had higher northern squawfish CI's in the spring. In The Dalles tailrace, the CI dropped from 1.5 in the spring to 0.4 during the summer sampling. The drop at the Ice Harbor tailrace was from 4.8 to 0.5, although a relatively small sample of fish (N = 14) was collected during the spring.

During the spring period, northern squawfish taken from all tailrace areas had relatively high CI's (0.9 to 4.8) compared to fish from forebays and mid-reservoir locations (Table 3). Northern squawfish in forebays had moderately high CI's (0.6 to 1.5) and fish from mid-reservoir locations had CI's that were very low (0 to 0.2). Northern squawfish from the McNary upper location, within the Hanford reach, had a moderately high CI (1.5). During the summer, CI's of northern squawfish by location followed a similar pattern as observed in the spring (Table 3).

Sample sizes in the mid-reservoir locations were generally low (Table 3). In the Bonneville mid-reservoir location, however, 39 and 42 northern squawfish were collected in spring and summer, respectively. None of these fish contained juvenile salmonid prey in their guts, resulting in CI estimates **of zero** (Table 3). Northern squawfish CI's for the BRZ's within tailraces and forebays are given in Table 4. During the spring, northern squawfish CI's were particularly high at the BRZ's of Bonneville Dam tailrace, McNary Dam tailrace and forebay, and the Ice Harbor Dam tailrace, although sample size was fairly small in the BRZ's of Ice Harbor Dam tailrace and the McNary Dam forebay (Table 4). During the summer, the northern squawfish collected from the BRZ's of tailraces of Bonneville, John Day and McNary dams had high CI's (4.6-11.2); in contrast, The Dalles and Ice Harbor tailrace BRZ's had summer CI's near zero (Table 4).

Consumption indices estimated for northern squawfish at the BRZ'S of dam tailraces and forebays were significantly higher than CI's estimated for northern squawfish from the adjacent non-BRZ area (Table 5). In the spring, CI's averaged only 0.7 CI units greater in the BRZ's compared to outside. In the summer,

Table 4. Consumption indices (CI) of northern squawfish within dam BRZ's in the lower Columbia and Snake Rivers during 1990. See Table 3 for explanation of columns.

RESERVOIR Location (BRZ only)	N	CI	Bootstrap Summary			Quartiles	
			Mean	SD	CV	25th	75th
SPRING							
Bonneville Tr	89	2.5	2.5	0.3	13	2.3	2.7
BONNEVILLE							
Bonneville Fb	102	0.8	0.8	0.2	26	0.7	1.0
The Dalles Tr	41	0.2	0.2	0.1	55	0.2	0.3
THE DALLES							
The Dalles Fb	20	1.0	1.1	0.8	71	0.5	1.4
John Day Tr	50	0.9	0.9	0.1	16	0.0	1.0
JOHN DAY							
John Day Fb	34	1.6	1.7	0.9	50	1.0	2.2
McNary Tr	60	2.4	2.4	0.2	9	2.2	2.6
MCNARY							
McNary Fb	17	7.8	8.5	5.5	65	4.4	11.5
Ice Harbor Tr	14	4.8	5.5	4.2	77	2.4	7.1
SUMMER							
Bonneville Tr	109	4.6	4.6	0.9	20	4.0	5.2
BONNEVILLE							
Bonneville Fb	89	2.2	2.2	0.6	29	1.8	2.7
The Dalles Tr	63	0.0	0.0	0.0	61	0.0	0.1
THE DALLES							
The Dalles Fb	25	2.8	2.8	1.1	39	1.2	3.6
John Day Tr	50	6.3	6.3	0.7	11	5.8	6.8
JOHN DAY							
John Day Fb	11	0.0	0.0	0.0	114	0.0	0.0
McNary Tr	50	11.2	11.2	1.0	9	10.5	12.0
MCNARY							
McNary Fb	8	0.0	0.1	0.1	78	0.0	0.1
Ice Harbor Tr	79	0.0	0.0	0.0	88	0.0	0.0

Table 5.   Comparison of mean northern squawfish CI's within the boat restricted zone (BRZ) versus outside the BRZ in selected dam tailraces (Tr) and forebays (Fb).   Only locations where sample size (N) was at least 15 northern squawfish were compared.   P is the probability that means were equal using a Mann-Whitney U test upon the 500 bootstrapped estimates for each mean.

RESERVOIR Location		BRZ			Outside BRZ			P
		Mean	SD	N	Mean	SD	N	
SPRING								
Bonneville	Tr	2.5	0.3	89	1.8	0.5	60	x.001
BONNEVILLE								
Bonneville	Fb	0.8	0.2	102	0.1	0.1	51	**<.001**
THE DALLES								
John Day	Tr	0.9	0.2	50	0.7	0.2	27	**<.001**
JOHN DAY								
McNary	Tr	2.4	0.2	60	1.6	0.4	17	x.001
SUMMER								
Bonneville	Tr	4.6	0.8	109	0.3	0.1	45	<.00l
BONNEVILLE								
Bonneville	Fb	2.2	0.4	89	0	0	50	x.001
THE DALLES								
The Dalles	Fb	2.8	1.2	25	0.2	0.0	36	**<.001**
John Day	Tr	6.3	0.5	50	0	0	46	**<.001**
JOHN DAY								
McNary	Tr	11.2	1.0	50	2.6	2.1	25	**<.001**
MCNARY								
Ice Harbor	Tr'	0.0	0.0	79	0	0	33	**<.001**

'Mean CI within the BRZ was 2.453-3 (SD = 2.153-3); rounding causes 0.0 for Ice Harbor Tr BRZ.

however, northern squawfish consumption differences between adjacent areas were much greater, averaging 4.0 CI units. The most dramatic difference occurred in the John Day and McNary tailraces where BRZ consumption indices were 6.3 and 8.7 CI units higher, respectively, than outside the BRZ (Table 5). Ice Harbor tailrace BRZ and non-BRZ northern squawfish consumption rates were very low in the summer, although the CI in the BRZ was still significantly higher than the CI measured outside of the BRZ (P < .001; Table 5). Northern squawfish CI's from both the tailrace and forebay BRZ's were higher than adjacent zones (Table 5). Higher northern squawfish CI's within BRZ's occurred in all reservoirs where adequate tests could be made (Table 5).

Our original intent was to estimate reservoir-wide consumption indices by combining samples from all locations in a reservoir for a given time period. Several results suggested that this strategy was not the best way to accurately index consumption in a reservoir. First, catches in different parts of a reservoir were usually very different due to the difficulty of collecting northern squawfish at mid-reservoir locations (Table 2). Unbalanced catches of predators would bias reservoir-wide CI's toward those locations where the greatest number of predators were caught - usually the BRZ's within tailraces and forebays. Secondly, comparisons of northern squawfish CI's in the BRZ's versus the CI's in adjacent, non-BRZ areas of the tailraces and forebays (see section above: Table 5) indicated that areas very near dams (BRZ's) had especially high predation rates. Tailrace and forebay areas outside the BRZ's usually had estimates that were more similar to mid-reservoir estimates than to the adjacent BRZ (Tables 3 and 5). Finally, low catches and many empty northern squawfish guts at several mid-reservoir locations caused their CI's to be zero. Although juvenile salmonid consumption could be zero or very low in some mid-reservoirs, complete lack of northern squawfish predation upon salmonids (zero CI) seems unlikely based upon earlier data from John Day Reservoir (Poe et al. 1988; Vigg et al. 1988).

For the above reasons, and to increase sample size,

Table 6. Reservoir-wide (excluding BRZ's at dams) CI's of northern squawfish during 1990 sampling in the lower Columbia and Snake Rivers. See Table 3 for explanation of columns.

RESERVOIR (excluding BRZ's)	N	CI	Bootstrap Summary			Quartiles	
			Mean	SD	CV	25th	75th
SPRING							
BONNEVILLE	97	0.0	0.0	0.0	141	0.0	0.0
THE DALLES	58	0.1	0.1	0.0	74	0.0	0.1
JOHN DAY	27	0.5	0.6	0.4	73	0.3	0.8
MCNARY	49	0.2	0.2	0.1	69	0.1	0.2
SUMMER							
BONNEVILLE	96	0	0	0	-	0	0
THE DALLES	133	0.0	0.0	0.0	106	0.0	0.0
JOHN DAY	37	0.2	0.2	0.1	78	0.1	0.2
MCNARY	83	0.1	0.1	0.1	54	0.1	0.2

"reservoir-wide" consumption was estimated by combining all samples collected between two dams, except those samples from the forebay and tailrace BRZ's (see Figure 2). Northern squawfish reservoir-wide CI's were quite low (< 1.0) in spring and summer (Table 6). In the spring period, the rank order of northern squawfish CI's, from lowest to highest, was Bonneville, The Dalles, McNary and John Day reservoirs. The inter-quartile ranges of the four reservoirs did not overlap (Table 6), suggesting northern squawfish consumption rates may differ among some reservoirs. In the summer, mean CI's of northern squawfish in Bonneville and The Dalles reservoirs were near zero. Out of 229 gut samples examined from these reservoirs in the summer, only 2 salmonids were recovered. The CI's for northern squawfish from John Day and McNary reservoirs were higher than CI's of northern squawfish in Bonneville and The Dalles reservoirs (Table 6).

Diet Summary of Northern Squawfish

Tables 7-12 summarize diet information. Diet summaries by location (tailrace, mid-reservoir and forebay) are in Tables 7 and 8; Tables 9 and 10 have information for BRZ's only, and Tables 11 and 12 summarize reservoir-wide (excluding BRZ's) northern squawfish gut content data.

In the laboratory, 1,598 northern squawfish gut samples were analyzed. The overall diet of squawfish was dominated by fish and crustaceans (45% and 37%, respectively: Table 7). Fish were the most important prey item for northern squawfish from the BRZ areas (Table 9). In contrast, crustaceans were the dominant prey item of northern squawfish in reservoir-wide areas, except in the John Day reservoir (Table 11). Crayfish made up the greatest portion of crustacean weight. Amphipods were also present, especially in small northern squawfish (<350 mm FL). During the summer sampling period, insects and plants also became important in the reservoir area (8.3% and 8.9%, respectively).

Using diagnostic bone counts, 939 juvenile salmonids were found in 435 northern squawfish; 18 other northern squawfish

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Table 7.   Gut content of northern squawfish at locations in the lower Columbia and Snake Rivers during 1990.   Gut contents (%) are the mean of percentages of individual northern squawfish that had non-empty guts.   Crust. = crustacean; Moll. = mollusk.   Tr=Tailrace, Fb=Forebay, Mr=Mid-reservoir, and Up=Upper reservoir.

RESERVOIR Location	N	Mean gut wt. (9)	% empty guts	GUT CONTENTS (%)					
				Fish	Crust.	Moll.	Insect	Plant	Other
SPRING									
Bonneville Tr	149	**11.21**	32.2	69.2	22.1	6.0	1.8	1.0	0.0
BONNEVILLE									
Bonneville Fb	153	**7.10**	30.7	30.4	61.8	2.4	0.0	1.9	3.5
Bonneville Mr	39	**3.12**	15.4	21.7	58.3	2.7	9.1	8.1	0.0
The Dalles Tr	48	**10.12**	33.3	78.7	20.7	0.0	0.0	0.6	0.0
THE DALLES									
The Dalles Fb	38	10.39	25.0	40.7	38.9	0.0	4.0	10.1	6.2
The Dalles Mr	15	4.09	20.0	4.7	79.5	8.0	2.9	1.4	3.4
John Day Tr	77	7.26	20.8	44.6	40.8	1.9	6.3	5.4	1.0
JOHN DAY									
John Day Fb	38	15.04	26.3	75.0	10.7	0.0	10.7	0.0	3.6
John Day Mr	6	1.54	16.7	0.0	80.0	0.0	20.0	0.0	0.0
McNary Tr	77	13.40	7.8	87.2	11.2	0.1	1.4	0.0	0.2
MCNARY									
McNary Fb	24	18.24	12.5	81.0	15.6	0.0	3.4	0.0	0.0
McNary Mr	9	14.49	33.3	16.7	80.9	0.0	0.0	0.0	2.4
McNary Up	33	5.27	33.3	40.0	28.5	2.8	14.9	0.5	13.4
Ice Harbor Tr	14	17.55	14.3	82.8	0.0	0.0	6.3	10.9	0.0
SUMMER									
Bonneville Tr	155	8.12	45.2	53.4	35.3	3.0	0.0	4.4	3.9
BONNEVILLE									
Bonneville Fb	139	10.37	41.7	25.6	48.3	2.4	9.2	5.8	8.9
Bonneville Mr	42	4.32	16.7	7.4	59.8	3.3	14.4	12.7	2.4
The Dalles Tr	67	7.67	62.7	24.2	41.3	3.4	3.3	17.0	10.7
THE DALLES									
The Dalles Fb	61	4.56	42.6	11.2	63.9	0.8	8.7	12.2	3.2
The Dalles Mr	51	2.65	23.5	4.2	43.1	0.0	33.9	9.8	8.8
John Day Tr	96	4.37	36.5	57.0	29.9	4.6	0.1	5.0	3.4
JOHN DAY									
John Day Fb	16	1.30	68.8	40.0	20.0	0.0	40.0	0.0	0.0
John Day Mr	7	4.00	42.9	21.7	73.1	0.0	2.7	2.5	0.0
McNary Tr	75	6.26	13.3	75.9	9.9	2.6	1.8	2.3	7.6
MCNARY									
McNary Fb	9	3.86	33.3	49.3	0.0	0.0	50.7	0.0	0.0
McNary Mr	13	6.90	7.7	24.7	66.9	0.0	0.0	0.0	8.4
McNary Up	36	8.45	11.1	21.0	45.9	1.3	5.7	20.0	6.1
Ice Harbor Tr	112	2.60	69.6	17.6	26.8	3.9	13.4	26.8	11.4

Table 8. Prey fish consumed by northern squawfish (SQF) at locations in the lower Columbia and Snake Rivers during 1990. FL =fork length; Mean Fish Wt. = mean prey fish mass (g) per predator; % smolts = percent of the total number of fish consumed that were juvenile salmonids. Tr=Tailrace, Fb=Forebay, Mr=Mid-reservoir, Up=Upper reservoir.

RESERVOIR Location		PREDATORS		PREY FISH CONSUMED					
	N	Mean FL (mm)	Mean Fish wt. (g)	Total # Smolts	# Smolts Per SQF	% Smolts	Total # Other Fish	% Other Fish
SPRING								
Bonneville Tr	149	392.7	**6.99**	**161**	1.1	**95.8**	7	**4.2**
BONNEVILLE								
Bonneville Fb	153	391.5	**2.45**	**33**	**0.2**	80.5	8	19.5
Bonneville Mr	39	344.9	**0.89**	0	**0.0**	0.0	11	100.0
The Dalles Tr	48	426.6	**6.4**	32	0.7	91.4	3	**8.6**
THE DALLES								
The Dalles Fb	38	423.6	**4.81**	**15**	**0.4**	100.0		0.0
The Dalles Mr	15	346.3	**0.16**	0	0.0	0.0	1	100.0
John Day Tr	77	391.6	**5.29**	32	0.4	86.5	5 0	13.5
JOHN DAY								
John Day Fb	38	418.6	**10.77**	**34**	**0.9**	100.0	0	**0.0**
John **Day Mr**	6	351.0	**0**	0	**0.0**	-		-
McNary Tr	77	417.2	**11.83**	124	1.6	98.4	2	1.6
MCNARY								
McNary Fb	24	437.4	**15.63**	**29**	**1.2**	93.5	2	6.5
McNary Mr	9	429.6	**5.89**	1	0.1	100.0	0	0.0
McNary Up	33	398.1	**2.66**	21	0.6	95.5	1	4.5
Ice **Harbor Tr**	14	446.1	**13.58**	26	1.9	96.3	1	3.7
SUMMER								
Bonneville Tr	155	372.0	**3.97**	123	0.8	96.1	5	3.9
BONNEVILLE								
Bonneville Fb	139	369.9	**3.28**	**49**	**0.4**	86.0	8	14.0
Bonneville Mr	42	351.9	**0.27**	**0**	**0.0**	0.0	5	100.0
The Dalles Tr	67	403.7	**1.45**	**6**	0.1	75.0	2 2	25.0
THE DALLES								
The Dalles Fb	61	374.6	**0.56**	9	0.1	81.8	0	18.2
The Dalles Mr	51	346.2	**0.17**		0.0	100.0		0.0
John Day Tr	96	397.1	**2.4**	**6:**	0.7	100.0	0 1	0.0
JOHN DAY								
John Day Fb	16	399.5	**0.08**	**2**	0.1	**66.7**	0	33 0'0 3
John Day Mr	7	337.6	**0.24**	1	0.1	100.0		·.·
McNary Tr	75	406.8	**3.26**	136	1.8	97.1	4	2.9
MCNARY								
McNary Fb	9	381.6	**1.27**	4	0.4	100.0	0	0.0
McNary Mr	13	425.7	**1.01**	7	0.5	70.0	3	30.0
McNary Up	36	373.3	**1.29**	**22**	0.7	92.9	2	7.1
Ice **Harbor Tr**	112	403.5	**0.15**	6	0.1	100.0	0	0.0

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Table 9.   Diet summary of northern squawfish within dam BRZ's in the lower Columbia and Snake Rivers during 1990.   See Table 7 for explanation of columns.

KESEKVOIR Location (in BRZ)		N	Mean gut wt (9)	% empty guts	GUT CONTENTS (%)					
					Fish	Crust.	Moll.	Insect	Plant	Other
SPRING										
Bonneville	**Tr**	**89**	**16.28**	30.3	88.5	3.7	6.2	1.6	**0.0**	**0.0**
BONNEVILLE										
Bonneville	**Fb**	102	7.79	35.3	43.4	48.9	3.5	0.0	1.5	2.6
The Dalles	**Tr**	**41**	**6.71**	39.0	88.0	12.0	0.0	0.0	0.0	0.0
THE DALLES							0.0	...		
The Dalles	**Fb**	**21**	**13.23**	28.6	66.7	26.7	0.5	7.7	0.0	...
John Day	**Tr**	**50**	**8.08**	18.0	46.6	41.2			3.0	1.4
JOHN DAY							0.0	...		
John Day	**Fb**	**34**	15.99	23.5	76.9	**7.7**	0.0	10.6	0.0	3.8
McNary	**Tr**	**60**	**13.4**	6.7	91.0	**8.8**			0.0	0.2
MCNARY										
McNary	**Fb**	**17**	**23.3**	**5.9**	93.8	**6.3**	0.0	0.0	0.0	0.0
Ice **Harbor**	**Tr**	**14**	**17.55**	**14.3**	82.8	0.0	0.0	6.3	10.9	0.0
SUMMER										
Bonneville	**Tr**	109	9.37	33.9	60.2	29.8	**2.1**	0.0	4.3	3.6
BONNEVILLE										
Bonneville	**Fb**	**89**	**14.52**	**43.8**	39.0	40.5	0.0	...	5.8	10.7
The Dalles	**Tr**	**63**	**7.83**	**66.7**	28.9	37.4	0.0	4.0	20.3	9.5
THE DALLES							0.0	...		
The Dalles	**Fb**	**25**	**4.96**	**68.0**	49.1	37.5	0.4	10.2	0.1	0.0
John Day	**Tr**	**50**	**5.89**	**24.0**	91.6	2.6			5.3	0.2
JOHN DAY										
John **Day**	**Fb**	11	1.59	63.6	50.0	25.0	0.0	25.0	0.0	0.0
McNary	**Tr**	**50**	**4.92**	**22.0**	89.7	0.0	0.0	0.0	2.6	7.7
MCNARY										
McNary	**Fb**	8	3.86	25.0	49.3	0.0	0.0	50.7	0.0	0.0
Ice **Harbor**	**Tr**	**79**	**2.88**	**68.4**	19.9	16.5	4.0	11.6	32.4	15.6

Table 10. Prey fish consumed by northern squawfish (SQF) within dam BRZ's in the lower Columbia and Snake Rivers during 1990. See Table 8 for explanation of columns.

RESERVOIR Location (in BRZ)	N	Mean FL (mm)	Mean Fish wt. (g)	Total # Smolts	# Smolts Per SQF	% Smolts	Total # Other Fish	% Other Fish
PREDATORS			**PREY FISH CONSUMED**					
SPRING								
Bonneville Tr	**89**	**408.9**	10.82	136	1.5	**96.5**	5	3.5
BONNEVILLE								
Bonneville Fb 102		402.2	3.43	32	0.3	**88.9**	4	11.1
The Dalles Tr 41		430.8	4.08	30	0.7	100.0	0	0.0
THE DALLES								
The Dalles Fb 21		435.2	8.14	14	0.7	100.0	0	0.0
John Day Tr 50		395.2	6.13	24	0.5	96.0	1	4.0
JOHN DAY								
John Day Fb	**34**	**417.4**	11.97	32	0.9	100.0	0	0.0
McNary Tr	**60**	412.9	12.37	108	1.8	100.0	0	0.0
MCNARY								
McNary Fb	**17**	446.1	21.88	28	1.6	96.6	1	3.4
Ice **Harbor Tr 14**		446.1	13.58	26	1.9	96.3	1	3.7
SUMMER								
Bonneville Tr	109	**375.9**	5.63	122	1.1	96.1	5	3.9
BONNEVILLE								
Bonneville Fb	**89**	388.8	5.1	49	0.6	**92.5**	**4**	7.5
The Dalles Tr	**63**	406.1	1.54	6	0.1	75.0	**2**	25.0
THE DALLES								
The Dalles Fb	**25**	**390.3**	1.37	**8**	**0.3**	88.9	**1**	**11.1**
John Day Tr	**50**	429.1	4.62	**65**	**1.3**	**100.0**	**0**	**0.0**
JOHN DAY								
John Day Fb	**11**	**405.1**	**0.12**	**2**	**0.2**	**66.7**	**1**	**33.3**
McNary Tr	**50**	**418.1**	3.82	**118**	**2.4**	**96.7**	**4**	**3.3**
MCNARY								
McNary Fb	**8**	**392.9**	1.43	**4**	**0.5**	100.0	**0**	**0.0**
Ice **Harbor Tr**	**79**	**411.2**	0.22	**6**	**0.1**	100.0	**0**	**0.0**

Table 11.   Diet summary of northern squawfish in reservoir-wide (excluding BRZ's at dams) areas in the lower Columbia and Snake Rivers during 1990 sampling.   See Table 7 for explanation of columns.

RESERVOIR (excluding BRZ's)	N	Mean gut wt (g)	% empty guts	GUT CONTENTS (%)					
				Fish	Crust.	Moll.	Insect	Plant	Other
SPRING									
								2.6	
Bonn. Tailrace	60	3.11	35	38.6	51.3	5.5	2.0	4.8	0.0
BONNEVILLE				17.4	70.1	1.3	3.8	..~	2.6
THE DALLES	27	5.99	17.5	21.4	55.7	4.4	2.8	11.1	4.6
JOHN DAY	49	9.19	22.2	52.7	37.6	0.2	9.5	0.0	0.0
MCNARY		6.51	32.7	35.8	40.6	1.9	12.1	0.3	9.3
SUMMER									
							0.0		5.3
BONNEVILLE	96	3.98	27.7	15.4	60.4	5.6	15.1	8.7	4.8
THE DALLES	133	2.82	33.1	1.8	60.0	3.3	17.2	10.3	7.4
JOHN DAY	37	7.22	45.9	38.1	41.8	7.0	5.5	1.7	5.8
MCNARY	83	5.47	36.1	20.2	52.7	1.5	6.6	14.0	5.1

Table 12. Prey fish consumed by northern squawfish (SQF) in reservoir-wide areas in the lower Columbia and Snake Rivers during 1990 sampling. See Table 8 for explanation of columns.

RESERVOIR (excluding BRZ's)	PREDATORS		PREY FISH CONSUMED					
	N	Mean FL (mm)	Mean Fish wt. (g)	Total # Smolts	# Smolts Per SQF	% Smolts	Total # Other Fish	% Other Fish
SPRING								
Bonn. Tailrace	60	369.2	1.33	25	0.4	92.6	2	7.4
BONNEVILLE	97	363.1	2.07	3	<0.1	14.3	18	85.7
THE DALLES	59	381.9	1.78	9	0.2	75.0	2	25:0
JOHN DAY	27	413.7	6.35	18	0.7	90.0	2	10 0
MCNARY	49	406.5	2.94	23	0.5	92.0		8:0
SUMMER								
Bonn. Tailrace	46	361.1	0.04	0	0.0	0.0	0	-
BONNEVILLE	96	344.3	0.14	2	0.0	66.7	1	100.0
THE DALLES	133	356.7	0.07	19	<0.1	.....	4	33.3
JOHN DAY	37	375.7	1.49		0.5	82.6		17.4
MCNARY	83	385.2	0.72	29	0.3	85.3	5	14.7

guts contained salmonid vertebrae or other non-diagnostic bones. The highest number of salmonids per gut were generally found in tailrace areas. Squawfish at mid-reservoir sites had the lowest number of **salmonids·gut^{-1},** except at the upper McNary location (Table 8). Northern squawfish within BRZ areas contained much higher numbers of juvenile salmonids (0.9 **salmonids·gut^{-1};** Table 10) than predators collected in the reservoir-wide areas (0.2 **salmonids·gut^{-1};** Table 12). Guts from northern squawfish collected in the spring period contained more juvenile salmonids than squawfish sampled in the summer. The spring samples contained fewer empty guts (25%) than the summer samples (41%; Table 7). The number of salmonids per gut (spring 0.7; summer 0.5) and prey fish weight per gut (spring 6.1 g; summer 2.0 g) were higher during the spring sampling period (Table 8), probably because of slower evacuation rates during spring when temperature was lower.

Other species of prey fish comprised only 7% of the total number of fish ingested by northern squawfish. In reservoir-wide areas (Table 12), 26% of the prey fish consumed were non-salmonids, while only 4% of the prey fish consumed were non-salmonids in the BRZ zones (Table 10). Sculpins made up 63% of the other prey fish category and were mostly found in predators collected around Bonneville Dam and at Bonneville mid-reservoir area.

Age Determination of Northern Squawfish

Use of otoliths for determining ages of northern squawfish proved unsuccessful due to problems encountered while trying to prepare the otoliths for viewing. Most otoliths were brittle and shattered easily when ground with fine grit emery paper or sectioned with a dremmel tool. For these reasons we abandoned the use of otoliths for age determination. Ageing of subsamples of northern squawfish with scales and opercles is progressing.

DISCUSSION

The goal of predation indexing is to provide a ranking of locations and reservoirs throughout the Columbia River Basin according to the intensity of predation upon juvenile salmonids. Predation indexing will require integration of consumption rate data with predator abundance data, which has not been completed. We have, however, provided some preliminary observations based upon the results of northern squawfish consumption indexing.

Northern squawfish consumption indices during 1990 were particularly high near hydroelectric projects, especially during the summer. Consumption indices tended to be several times higher, often an order of magnitude or more, in tailrace and forebay BRZ's (Table 4) compared to CI estimates made by pooling predators from the non-BRZ portions of the reservoir (Table 6). The CI's in The Dalles tailrace BRZ and John Day forebay BRZ were exceptions to this pattern, having somewhat lower northern squawfish CI's than was observed in the BRZ's at the other dams. Such exceptions might be explained by sample timing, dam operation, project design (see Figure 2, e.g.) or other factors.

Catch per unit effort by ODFW and FWS electrofishing was relatively high near dams (preliminary data in Vigg and Burley 1990b) suggesting predator abundance may be high at these sites. Abundant predators and high consumption rates may result in significant juvenile salmonid losses near dams. Juvenile salmonids may also be more susceptible to predators immediately downstream of dams because of stress, disorientation, or injury caused by passage through the dam.

Sampling in the mainstem Columbia River reservoirs during 1990 was scheduled to coincide as close as possible with historical salmonid passage patterns. Examination of 1990 juvenile salmonid passage indices showed that sample scheduling was generally successful for consumption indexing (Figure 5). We used juvenile salmonid passage indices from individual dams as general indicators of salmonid abundance near that dam (forebay and tailrace), and also in the immediate, downstream reservoir. In the McNary and John Day reservoirs, sampling coincided well
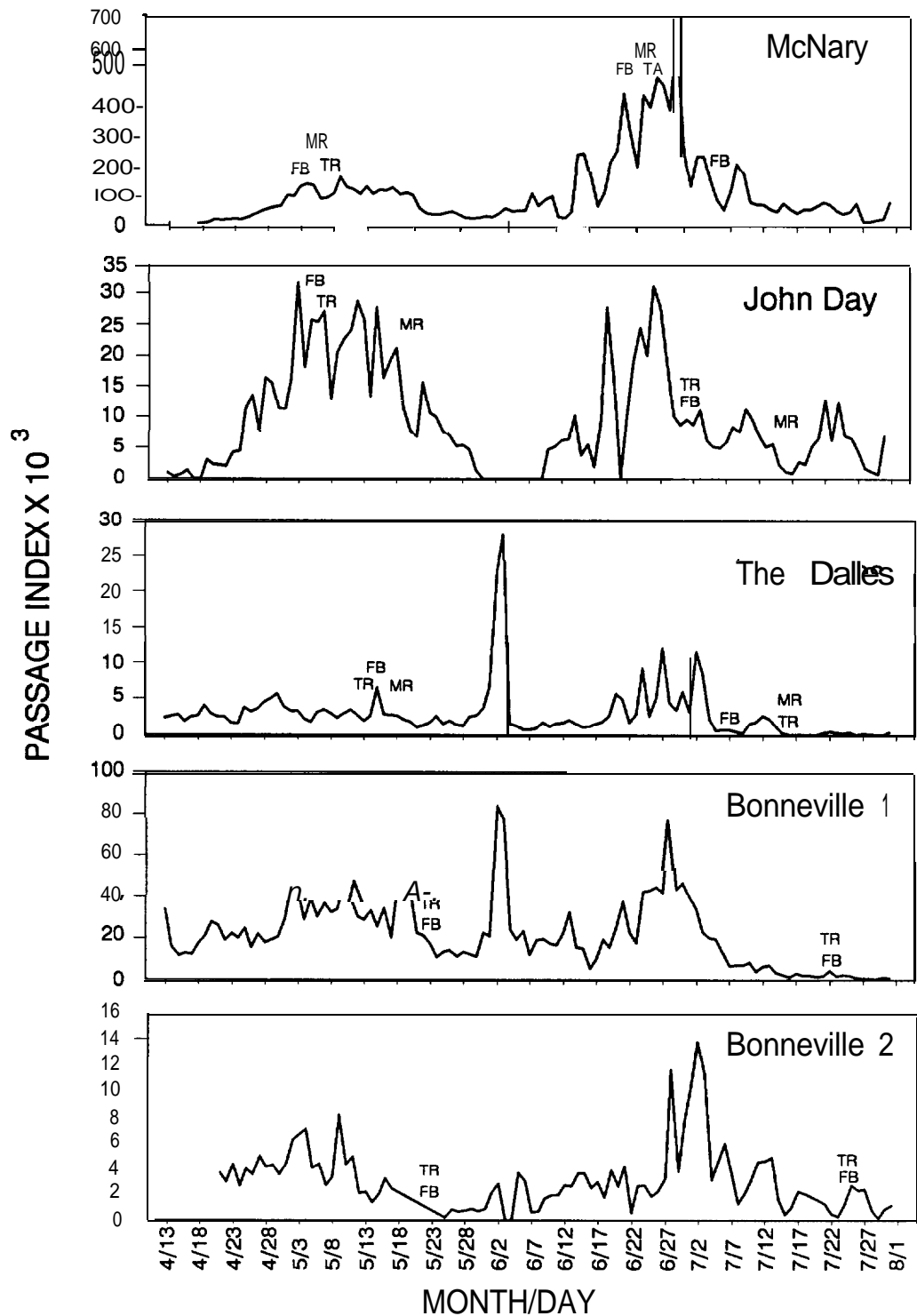
Figure 5. Timing of Consumption Index sampling during 1990 with respect to juvenile salmonid passage indices at mainstem dams. Approximate sample times for tailrace (TR), forebay (FB), and the immediate downstream mid-reservoir (MR) locations are shown in a panel. The MR locator in the John Day panel, for example , actually represents sampling within The Dalles mid-reservoir. Passage data from the Fish Passage Center 1990 Biweekly Reports.

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with the spring and summer salmonid out-migrations (Figure 5).
In The Dalles and Bonneville reservoirs, spring sampling was
toward the end of the period of highest salmonid abundance, when
passage indices were gradually declining, but still fairly high.
Summer sampling in the two lower reservoirs, especially in The
Dalles Reservoir, missed the largest smolt passage period (about
June, 20 through July, 10). Low prey densities during our summer
sampling in The Dalles Reservoir might explain the low CI's
observed in The Dalles forebay and mid-reservoir locations (Table
3). On the other hand, northern squawfish consumption indices
were moderate to high in The Dalles forebay, Bonneville forebay
and Bonneville tailrace even though passage indicies were low
during sampling at these locations. This suggests that
consumption indices were not simply a reflection prey density and
consumption rate could be high even when passage was relatively
low.

Collecting northern squawfish was most difficult at mid-
reservoir locations, as expected, and considerably more fishing
effort (at least double) would have been required to reach the
original mid-reservoir sampling targets (≥ 60 fish per two-day
period). The variability of small-sample CI estimates were,
however, narrow enough that rough CI comparisons could be made
 (CI/2 vs. CI vs. 2*CI, e.g.) with high statistical power (>90%).
Comparisons of CI estimates from tailrace and forebay locations
could be made with even greater confidence (higher power) because
of the larger samples and tighter relative variability about the
mean CI's.

In future studies, northern squawfish consumption and
predation indices from the lower Columbia River (1990, this
report), the lower Snake River (scheduled 1991) and the mid-
Columbia River (planned 1992) will be compared to provide a
relative ranking of juvenile salmonid losses to predators in
different reservoirs. Since sampling in the lower Columbia
River, the lower Snake River and the mid-Columbia River will be
conducted in separate years (1990-92), direct comparisons of
regional data will not be possible. The study design calls for

John Day Reservoir to be sampled each year (1990-92), providing a scaler for inter-annual effects. Predation in John Day Reservoir was also studied in 1983-86 and 1988 (Poe et al. 1988; Petersen et al. 1990), supplying additional data for comparisons.

Use of a northern squawfish bioenergetics model will provide an alternative means of estimating juvenile salmonid consumption rate. Consumption rate estimation with fish energetic models has been advocated elsewhere (Rice and Cochran 1984; Bartell et al. 1986). Weight change of cohorts of fish will be used in modeling consumption rate and salmonid ration. Ongoing work on the age of northern squawfish in lower Columbia and Snake River reservoirs is required so average weights of cohorts can be estimated at different times from spring to fall.

LITERATURE CITED

Bagenal, T. B. and F. W. Tesche. 1978. Age and growth. Pages 101-136 In: T. B. Bagenal (ed.) Methods for assessment of fish production in freshwater, 3rd Edition. Blackwell Scientific Publications, Oxford, England.

Bartell, S. M., J. E. Breck, R. H. Gardner and A. L. Brenkert. 1986. Individual parameter perturbation and error analysis of fish bioenergetics models. Can. J. Fish. Aquat. Sci. 43:160-168.

Beyer, J. M., G. Lucchetti, and G. Gray. 1988. Digestive tract evacuation in northern squawfish (_Ptvchocheilus oreaonensis_). Can. J. Fish. Aquat. Sci. 45:548-553.

Efron, B. and R. Tibshirani, 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science, 1:54-77.

Fickeisen, D. H., D. D. Dauble, and D. A. Neitzel. 1990. Proceedings of the predator-prey modeling workshop, Friday Harbor, Washington, May 16-19, 1989. Final contract (DE-AC06-76RLO-1830) completion report to Bonneville Power Administration, Portland, Oregon.

Hewett, S. W. and B. L. Johnson. 1987. A generalized bioenergetics model of fish growth for microcomputers. University of Wisconsin Sea Grant Institute, Report No. WIS-SG-87-245.

Hewett, S. W. and B. L. Johnson. 1989. A general bioenergetics model for fishes. American Fisheries Society Symposium, 6:206-208.

Jearld, W. E. 1983. Age determination. Pages 301-323 In: L. A. Nielson and D. L. Johnson (eds.), Fisheries techniques. Am. Fish. Soc., Bethesda, MD.

McConnell, W. J. 1952. The opercular bone as an indicator of age and growth of the carp, _Cynrinus carpio_ Linnaeus. Trans. Am. Fish. Soc. 81:138-149.

Nigro, A. A., S. Vigg and C. Burley. 1990. Development of a system-wide predator control program: Stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River Basin. Annual Progress Report, August 1988 - September 1989, Project Summary. Project Number 82-028, Bonneville Power Administration, Portland, Oregon.

Petersen, J. H., M. G. Mesa, J. Hall-Griswold, W. C. Schrader, G. W. Short and T. P. Poe. 1990. Magnitude and dynamics of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1989-1990. Bonneville Power Administration, Portland, Oregon.

Poe, T. P. and B. E. Rieman (eds.). 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir, 1983-86. Final Report, (Contracts DE-A179-82BP34796 and DE-A179-82BP35097) Bonneville Power Administration, Portland, Oregon.

Rice, J. A. and P. A. Cochran. 1984. Independent evaluation of a bioenergetics model for largemouth bass. Ecology 65:732-739.

Rieman, B. E., R. C. Beamesderfer, S. Vigg and T. P. Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia Reservoir: Part IV. Estimated total loss and mortality of juvenile salmonids to northern squawfish, walleye, and smallmouth bass. In: Poe, T. P. and B. E. Rieman (eds.), 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir, 1983-86. Final Report, (Contracts DE-A179-82BP34796 and DE-A179-82BP35097) Bonneville Power Administration, Portland, Oregon.

Scoppettone, G. G. 1988. Growth and longevity of the Cui-ui and longevity of other catostomids and cyprinids in western North America. Trans. Am. Fish. Soc. 117:301-307.

Seaburg, K. G. 1957. A stomach sampler for live fish. Prog. Fish Cult. 19:137-139.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel, 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia River Reservoir: Part II. Consumption rates of northern squawfish, walleye, smallmouth bass, and channel catfish. In: Poe, T. P. and B. E. Rieman (eds.), 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir, 1983-86. Final Report, (Contracts DE-A179-82BP34796 and DE-A179-82BP35097) Bonneville Power Administration, Portland, Oregon.

Vigg, S. and C. C. Burley. 1990a. Report A - Developing a predation index and evaluating ways to reduce juvenile salmonid losses to predation in the Columbia River. In: Nigro, A. A. (ea.), 1990. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia River Basin. 1989 Annual Progress Report. Bonneville Power Administration, Portland, Oregon.

Vigg, S. and C. C. Burley. 1990b. DRAFT REPORT. Summary of catch per unit effort (CPUE) of commercial fisheries, sport reward fisheries, dam angling, and indexing.

Appendix A.   Description of consumption indexing database.

DATABASE DEVELOPMENT AND DATA PROCESSING

        A relational database program was used to organize and store
field and laboratory data. A relational database is a set of
linked tables, each table containing a particular category of
data(i.e., transect data and predator data). Data integrity is
enhanced as information is shared among tables. For example, if
a column is defined in one table to have a particular data type,
a new table with the same column will automatically have the same
data type. Common columns among tables allow a user to
manipulate several tables at a time. Two or more tables that
share at least one column can be combined for query or data
output purposes. Several relational commands are available that
combine identical rows and/or columns. Redundant data entry and
associated error are also decreased by having an efficient
database.

TABLE AND COLUMN DEFINITIONS

        Consumption indexing field data were separated into two
master tables and linked by a collection number (COLLECT#. Figure
Al). Each transect was assigned a unique "collection number" and
each predator within a transect was given a unique "predator
number"(NUMBER). Transect information was placed into the
MTRNSECT table and predator data within transects were entered to
the MPREDATR table.

As each transect possibly contained several predators and each
predator was related to only one transect, a one-to-many
relationship was represented between the two tables. This
arrangement permitted one-time entry of transect data for all of
the predators collected within that transect, reducing table size
and allowing individual predator data to be stored in a separate
table. Diet data were contained in a table named MPREYDAT which
was linked to the MPREDATR table by the common columns COLLECT#
and NUMBER, and to the MTRNSECT table by COLLECT#.(Figure Al).
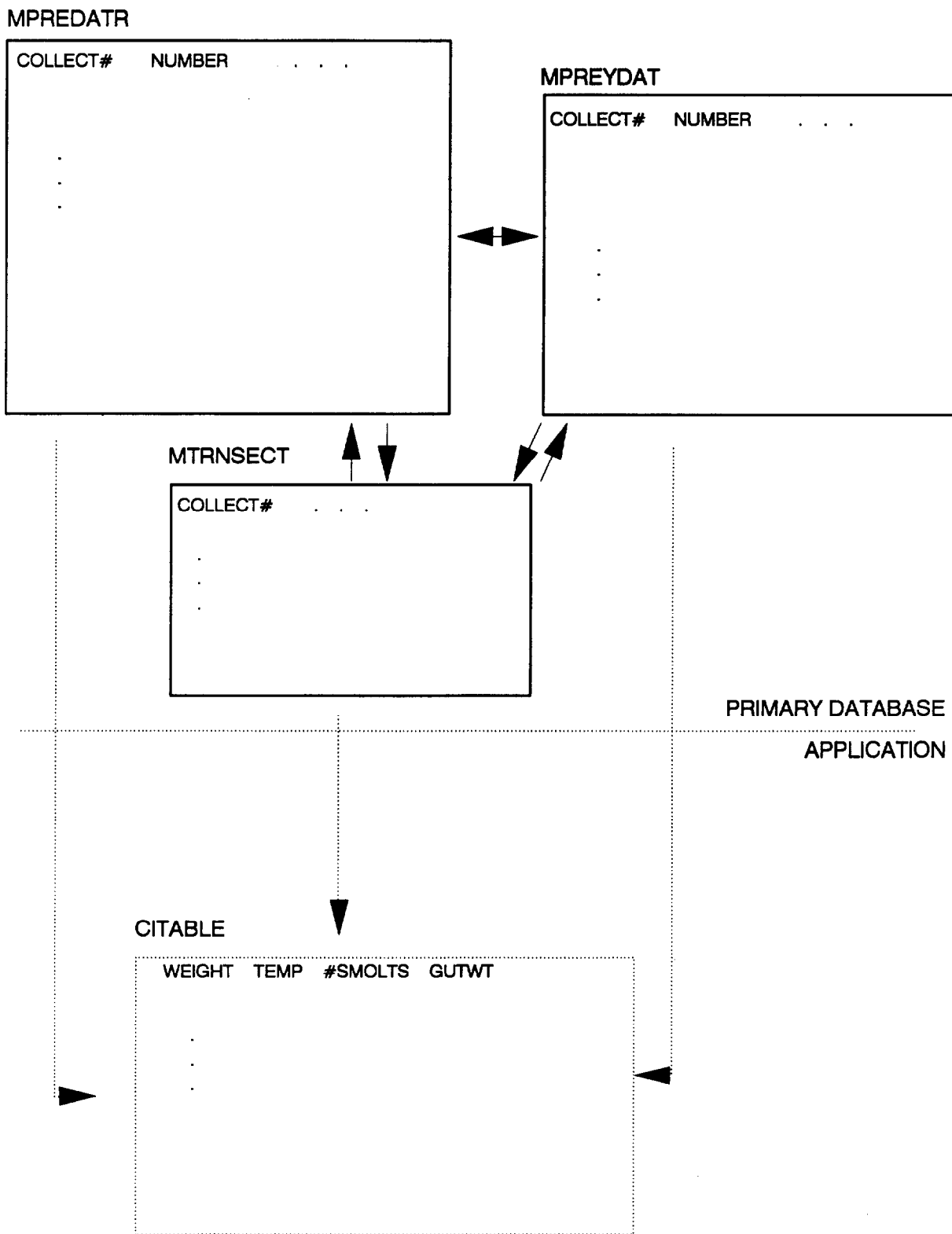
MPREDATR

COLLECT#	NUMBER	. . .
.		
.		
.		

MPREYDAT

COLLECT#	NUMBER	. . .
.		
.		
.		

MTRNSECT

COLLECT#	. . .
.	
.	
.	

PRIMARY DATABASE

APPLICATION

CITABLE

WEIGHT	TEMP	#SMOLTS	GUTWT
.			
.			
.			

Figure A1. Schematic representation of master tables and application of relational design. Only common columns are shown. Rows represent each unique set of data. Table name is above each box. Variable names are listed in Table A1.

MPREYDAT contained diet information for every predator from which a stomach sample was taken. Column names and data types were defined for each appropriate table and expressions were written for computed columns. Table Al lists the column names and data types for each master table and displays which columns were common between tables.

DATA ENTRY AND EDITING
     Keyboard data-entry was facilitated by defining forms that closely resembled the data sheets. Entry errors were minimized by limiting the values or text that could be entered into a particular field on a form. Commands for sorting were used to arrange rows of data sequentially for tabular editing. A hard copy of each master table was printed and proofed for errors. After a final edit the tables were ready for creating subsets to be used for data analysis.

COMBINING VARIABLES AND PROJECTING DATA SUBSETS
     Several options were available which joined selected columns/variables from two or more tables. Subsets of the new tables were used for data analysis. For example, catch summary information for species by location and date was extracted from a table that contained selected predator and transect data. Datasets that were to be analyzed by other software applications were exported to appropriate files, such as ASCII or Lotus spreadsheet files.

FILE ARCHIVES
     The entire database, including structure definition and indices for keyed columns was stored as three files. The working database was written to a hard disk on an IBM AT. Two archival copies were kept on floppy diskettes and stored separately. A second copy of the working set was stored on a separate microcomputer. Revisions from the first working copy were updated to the archival files on a weekly basis.

TABLE Al.   DATABASE VARIABLES AND DESCRIPTIVE DEFINITIONS FOR
            PRINCIPLE TABLES

TABLE MTRNSECT

VARIABLE NAME	**DESCRIPTION**
LOCATION	6 digit code defines spatial data
DATE	Sampling date
COLLECT#	Collection number unique for each transect
CREW	
BOAT	
GEAR	Code for capture method
TEMP	Recorded temperature
WEATHER	Code for weather condition
STARTTIM	Military time for start of transect
STOPTIME	Military time for end of transect
COMMENTS	Text for unusual circumstances
RANDOM	Designates whether transect was selected randomly (for CPUE)

TABLE MPREDATR

COLLECT#	Common variable linked to MTRNSECT
NUMBER	Predator number unique for each predator within a transect
SPECIES	Text value (3 characters)
FORKLENG	Forklength
WEIGHT	Predator weight
SEX	One digit code
SCALE	One digit code to indicate whether a scale sample was taken
MATURITY	Indicated sexual maturity
DISPOSTN	Code to indicate disposition of the predator
COMMENT2	Text to remark on unusual characteristics

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TABLE Al. (Continued) DATABASE VARIABLES AND DESCRIPTIVE
DEFINITIONS FOR PRINCIPLE TABLES

TABLE MPREYDAT

COLLECT#	Common variable linked to MPREDATR and MTRNSECT
NUMBER	Common variable linked to MPREDATR
PROCESS#	Lab number for each predator
ANALYZER	
FISHWT	Grams of fish found in stomach sample
PREY1	Grams of prey item #l excluding fish
CODE1	ID code for PREY1
PREY2	Grams of prey item #2 excluding fish
CODE2	ID code for PREY2
OTHERPRY	Grams of prey item #3 excluding fish
CODE3	ID code for OTHERPRY
TOTALWT	Sum(in grams) of all prey items
#SMOLTS	Number of smolts identified/sample
#SCULPIN	Number of sculpins identified/sample
#OTHER	Number of other fish identified/sample
#UNIDSAL	Incidence of unidentified salmonids/sample
#UNIDOTH	Incidence of unidentified other fish/sample
COMMENT3	Remarks about prey items

Appendix B. DRAFT Summary Report - Effects of temperature upon respiration rates of northern sguawfish (<u>Ptvchocheilus oreaonensis</u>).

NORTHERN SQUAWFISH 0, CONSUMPTION RATE: EFFECTS OF TEMPERATURE

by

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Abstract

Northern squawfish, Ptvchocheilus oresonensis, (live weight range: 0.225 - 1.973 kg) were caught by electrofishing in the Columbia River and held in continuous-flow tanks at 9, 15, 18, or 21°C. Fish were placed into temperature-controlled, flow-through respirometers which incorporated an automated dissolved 0, measuring system. 0, consumption data were collected at ca. 90 min intervals for >24 h. Mean ($\pm$ 2SE) standard 0, consumption rate of northern squawfish increased with acclimation temperature: 24.3 $\pm$ 2.2 $mg \cdot kg^{-0.67} \cdot h^{-1}$ at 9°C, 49.1 $\pm$ 6.6 $mg \cdot kg^{-0.67} \cdot h^{-1}$ at 15°C, 75.0 $\pm$ 8.7 $mg \cdot kg^{-0.67} \cdot h^{-1}$ at 18°C, and 85.9 $\pm$ 26.6 $mg \cdot kg^{-0.67} \cdot h^{-1}$ at 21°C. Q_{10} analysis showed that 0, consumption rate temperature sensitivity was greatest at the intermediate acclimation temperatures (15 - 18°C, Q_{10} = 4.10), moderate at the lower acclimation temperatures (9 - 15°C, Q_{10} = 3.23), and lowest at the higher acclimation temperatures (18 - 21°C, Q_{10} = 1.57). Overall Q_{10} was 2.86 (9-21°C). Generally, northern squawfish 0, consumption rates more closely approximated those of other predatory fishes rather than those of lacustrine, omnivorous cyprinids.

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Introduction

The northern squawfish, <u>Ptvchocheilus oreaonensis,</u> is a
predaceous cyprinid fish inhabiting fresh water habitats in
Oregon, Washington,' British Columbia and Alberta (Scott and
Crossman 1973). Squawfish predation on juvenile salmonid fishes
in the heavily modified Columbia River system has stimulated
research on squawfish bioenergetics, including the construction
of mathematical models (Rieman and Beamesderfer 1990). An
important component of bioenergetic models is standard metabolic
rate, the basal energy requirement for body maintenance (reviewed
by Fry 1971 and Brett and Groves 1979).

Our objective was to measure standard O_2 consumption rates, as a
measure of respiratory metabolism) for adult northern squawfish
at temperatures which spanned the summer conditions in the
Columbia River. We also compared northern squawfish O_2
consumption rates with those for other omnivorous species in the
same family and with other predaceous freshwater teleosts.

Materials and Methods

Adult northern squawfish were collected by electrofishing in the
Columbia River near Bonneville Dam on June 14, 1990. Fish were
quickly transported in oxygenated tanks to the USFWS Columbia
River Field Station laboratory and held in circular, flowing
water tanks (1.2 m diameter, 1400 L) for >3 wk at acclimation
temperatures of 9, 15, 18, or 21°C. Only three temperatures
could be maintained at one time, so fish were randomly assorted,
by weight class, into 9, 15 and 21°C acclimation groups. The
18°C group of fish consisted of remaining northern squawfish and
did not include as broad a range of weights as the other
temperature groups. Natural light cycles were maintained and
fish were fed juvenile salmonids (about 1 prey·day^{-1}) until
respiration experiments. Water source was the Little White

Salmon River, a tributary of the Columbia River.

Fish were inserted in appropriately sized, flow-through respirometers (5 L or 13 L) for O_2 consumption rate (MO_2) measurements. Respirometers were situated in 250-L, insulated fiberglass water baths which were interconnected with submersible pumps and siphons. Due to time and space constraints, experiments on fish at each acclimation temperature were all conducted within a several-day period. Experiments were conducted in the order: 9 (n=18), 15 (n=16), 21 (n=15), 18°C (n=16). Water temperature in the baths was regulated by thermostatted (YSI model 72 proportional temperature controllers) glass immersion heaters balanced against a continuous inflow of cold (8°C) water from the Little White Salmon River. Particle filters (Teel model 2P275/2P369) which trapped particles >25um, continuously cleaned water in the system. Water from the interconnected baths was pumped in excess to an insulated, plastic reservoir incorporating an overflow standpipe, which maintained a constant pressure head and flow of water to the respirometers. Outflowing water from the respirometers was split by a Y fitting into two tubes. One tube incorporated an in-line solenoid valve and led to a manifold with a calibrated, O_2 electrode (Nester model 617034) whereas the other tube returned water to the bath. The O_2 electrode was wired to a Nester digital O_2 meter (model 8500) and stripchart recorder (Soltec Model 310). Solenoids were wired to an electronic sprinkler timer (Toro model EL-12+) such that valves sequentially opened at ca. 9 min intervals, sampling water from respirometers with fish, respirometers without fish (blank controls), and a tube without a respirometer (inflow water). Water flow rates were measured by the timed collection of water from tank outflow tubes (when solenoids were closed). MO_2 ($mg \cdot kg^{-0.67} \cdot h^{-1}$) was calculated using:

$$MO_2 = (O_2 in - O_2 out)(Vw \cdot 60)(1000/M_b)^{0.67}$$

where: $O_2 in$ = inflowing $[O_2]$ in mg/L,

O_2out = outflowing $[O_2]$ in mg/L,

VW   = water flow in L/min, and

M_b = live body mass of fish in g.

Standard MO, was determined by calculating the mean of the two lowest MO, values measured over the 24+ h experiment for each fish. Mean MO_2s at each temperature were compared using ANOVA followed by appropriate hypothesis tests (Wilkinson 1988).

Results

Mean, standard, mass-independent MO, of northern squawfish increased with increasing acclimation temperature. Mean ($\pm$ 2SE) rates were: 24.3 $\pm$ 2.2 at 9°C, 49.1 $\pm$ 6.6 at 15°, 75.0 $\pm$ 8.7 at 18°, and 85.9 $\pm$ 26.6 at 21°. Data for individual specimens are shown in Table Bl. The increases between 9 and 15°, and between 15 and 18° were significant (p<0.05). Q_{10} analyses (Schmldt-Nielsen 1975) showed that MO, sensitivity was greatest at the intermediate acclimation temperatures (15 − 18°C, Q_{10} = 4.10), moderate at the lower acclimation temperatures (9 - 15°C, Q_{10} = 3.23), and lowest at the higher acclimation temperatures (18 - 21°C, Q_{10} = 1.57). The overall Q_{10} was 2.86 (9 - 21°C).

Discussion

Our northern squawfish data seem realistic as measures of standard metabolism because the rates approximate those of other species with similar feeding habits (Table B2). Also, our data are consistently below resting routine 0, consumption rates measured for the congeneric Sacramento squawfish, P. arandis (Table B2). Resting routine O_2 consumption rates (Cech 1990) are defined as those exhibited by quiescent fish, but not necessarily

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the lowest rates over the 24 h diurnal cycle. Cech et al. (1990)
measured resting routine 0, consumption rates for rainbow trout
which also consistently exceed standard 0, consumption rates
(Table B2).

Northern squawfish MO, temperature sensitivity varied with the
acclimation temperature range. Other species have also shown Q_{10}
variations through acclimation temperature ranges. For example,
MO_2 Q_{10}s for rainbow trout were 3.5 between 4 and 10°C and only
1.7 between 12 and 22°C (Muller-Feuga et al. 1978). Baltz et al.
(1982) calculated Q_{10}s ranging from 1.05 (10 - 15°C) to 3.21 (25 -
27.5°C) for speckled dace, Rhinichthys osculus (Cyprinidae).
Utah chub, Gila atraria (Cyprinidae), show standard MO, Q_{10}s
ranging from 2.24 (6 - 9°C) to 5.05 (12 - 18°C), as calculated
from Rajagopal and Kramer's (1978) data. The Sacramento
squawfish shows a reduced resting routine MO_2 temperature
sensitivity at moderate temperatures (15 - 20°C, Q_{10} = 1.20),
compared with those at more extreme temperatures (10 - 15°C, Q_{10} =
4.18; 25 - 30°C, Q_{10} = 2.36), as calculated from Cech's et al.
(1990) data. Curiously, this appears to be the opposite pattern
shown by the standard MO, data of its congener, northern
squawfish (Table Bl), albeit through a smaller temperature range.

Comparisons with other species in the family Cyprinidae show that
northern squawfish have higher standard MO,. Beamish (1964)
calculated standard MO, of carp, Cyorinus carnio, from
extrapolation of log MO, at various activity levels to zero
activity. Beamish and Mookherjii (1964) used the same technique
to calculate standard MO, of goldfish, Carrassius carpio.
Although the experimental temperatures do not coincide with those
used in our study, both carp and goldfish seem to have lower
standard MO_2s than northern squawfish (Table B2). Whereas both
carp and goldfish generally inhabit quiet or slowly moving water
and are omnivorous and generally do not chase moving prey such as
small fish, squawfish are predators (reviewed by Moyle 1976,
Scott and Crossman 1973). One might predict that northern

squawfish would have higher standard MO_2s, perhaps accompanying larger red muscle masses. Larger red muscle masses typify more active species (Bainbridge 1960, 1962), and red muscle has higher tissue 0, demands than white muscle (Gordon 1968, Lin et al. 1974, Itazawa and Oikawa, 1983). Red muscle mass comparisons of northern squawfish with other species have not yet been made.

Comparisons with other predatory species show that northern squawfish have similar MO_2s to rainbow trout, <u>Oncorhvnchus mvkiss,</u> and to walleye, <u>Stizostedion vitreum</u>. Using the extrapolation technique outlined above, Rao (1968) and Dickson and Kramer (1971) showed that both wild and hatchery rainbow trout have comparable MO_2s to northern squawfish (Table B2). Tarby (1981) used acrylic, flow-through respirometers similar to those which we used and showed that walleye have similar standard MO_2s to northern squawfish (Table B2). Both rainbow trout and walleye exist in the Columbia River system.

In conclusion, northern squawfish displayed standard MO_2s comparable to other predatory fishes in its environment. Northern squawfish standard MO, increased to varying extents with increasing acclimation temperature. Temperature sensitivity of northern squawfish standard MO, showed a peak at intermediate temperatures (15 - $18°C)$, compared with lower (9 - $15°C)$ and higher (18 - 21 $°C)$ temperatures. Future studies are needed to assess the effects of water current (swimming) on northern squawfish MO,.

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LITERATURE CITED

Bainbridge, R. 1960. Speed and stamina in three fish. J. Exp. Biol. 37:129-153.

Bainbridge, R. 1962. Training, speed and stamina in trout. J. Exp. Biol. 39:537-555.

Baltz, D.M., P.B. Moyle, and N.J. Knight. Competitive interactions between benthic stream fishes, riffle sculpin, Cottus cfulosus, and speckled dace, Rhinichthvs osculus. Can. J. Fish. Aquat. Sci. 39:1502-1511.

Beamish, F.W.H. 1964. Respiration of fishes with special emphasis on standard oxygen consumption. II. influence of weight and temperature on respiration of several species. Can. J. Zool. 42:177-188.

Beamish, F.W.H. and P.S. Mookherjii. 1964. Respiration of fishes with special emphasis on standard oxygen consumption. I. influence of weight and temperature on respiration of goldfish, Carrassius auratus L. Can. J. Zool. 42:161-175.

Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. J. Fish. Res. Bd. Can. 21:1183-1226.

Brett, J.R. and T.D.D. Groves. 1979. Physiological energetics. pp. 279-352. In: W.S. Hoar, D.J. Randall, and J.R. Brett (eds.) Fish physiology. Vol. 8. Academic Press, New York.

Cech, J.J., Jr. 1990. Respirometry. **In**: C.B. Shreck and P.B. Moyle (eds.) Methods in Biology of Fishes. Amer. Fish. **Soc.** Publ. Bethesda. (In press)

Cech, J.J., Jr., S.J. Mitchell, and M.J. Massingill. 1979. Respiratory adaptations of Sacramento blackfish, Orthodon microlenidotus (Ayres), for hypoxia. Comp. Biochem. Physiol. 63A:411-415.

Cech, J.J., Jr., S.J. Mitchell, D.T. Castleberry, and M. McEnroe. 1990. Distribution of California stream fishes: influence of environmental temperature and hypoxia. Env. Biol. Fish. 29:95-105.

Fry, F.E.J. 1971. The effect of environmental factors on the physiology of fish. pp. 1-98. **In**: W.S. Hoar and D.J. Randall (eds.) Fish physiology. Vol. 6. Academic Press. New York.

Dickson, I.W. and R.H. Kramer. 1971. Factors influencing scope for activity and active and standard metabolism of rainbow trout (Salmo sairdneri). J. Fish. Res. Bd. Can. 28:587-596.

Gordon, M.S. 1968. Oxygen consumption of red and white muscles from tuna fishes. Science 159:87-90.

Itazawa, Y. and S. Oikawa. 1983. Metabolic rates in excised tissues of carp. Experientia 39:160-161.

Lin, Y., G.H. Dobbs, III, and A.L. DeVries. 1974. Oxygen consumption and lipid content in red and white muscles of Antarctic fishes. J. Exp. Zool. 189:379-386.

Moyle, P.B. 1976. Inland fishes of California. Univ. Calif. Press. Berkeley.

Muller-Feuga, A., J. Petit, and J.J. Sabaut. 1978. The influence of temperature and wet weight on the oxygen demand of rainbow trout (<u>Salmo aairdneri</u> R.) in fresh water. Aquaculture 14:355-363.

Rajagopal, P.K. and R.H. Kramer. 1974. Respiratory metabolism of Utah chub, <u>Gila</u> <u>atraria</u> (Girard) and speckled **dace,** <u>Rhinichthvs</u> <u>osculus</u> (Girard). J.Fish Biol. 6:215-222.

Rao, G.M.M. 1968. Oxygen consumption of rainbow trout (<u>Salmo aairdneri</u>) in relation to activity and salinity. Can. J. Zool. 46:781-786.

Rieman, B.E. and R.C. Beamesderfer. 1990. Dynamics of a northern squawfish population and the potential to reduce predation on juvenile salmonids in a Columbia River reservoir. N.Amer. J. Fish. Manage. 10:228-241.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. 184. Ottawa.

Tarby, M.J. 1981. Metabolic expenditure of walleye (<u>Stizostedion vitreum vitreum</u>) as determined by rate of oxygen consumption. Can J. Zool. 59:882-889.

Wilkinson, L. 1988. SYSTAT: the system for statistics. SYSTAT, Inc. Evanston.

Table Bl. Mass (g), standard lengths (SL in cm), and standard, mass-independent metabolic rates $(mgO_2\ kg^{-2/3}\ hr")$ for fish at each acclimation temperature.

Temp 9°C			15°C			18°C			21°C		
Mass	SL	MO_2	Mass	SL	MO_2	Mass	SL	MO_2	Mass	SL	MO_2
903	36	21.4	665	37	46.2	908	39	56.8	1065	49	35.2
443	29	32.2	584	34	41.9	1161	42	73.0	1412	44	84.2
459	28	23.4	1181	39	57.7	958	41	49.7	1570	46	28.1
1561	42	22.6	1314	43	39.9	1268	44	66.7	1602	47	128.3
1856	43	27.8	1856	47	73.8	1144	42	93.9	512	33	145.7
1088	38	22.6	439	30	49.4	1106	40	81.4	740	38	58.7
448	31	19.2	415	31	28.7	1220	42	62.2	670	36	70.3
924	40	24.8	974	40	40.1	1008	42	72.9	225	25	36.9
976	41	22.0	1209	41	71.7	1340	45	59.4	444	32	226.0
1760	45	29.7	1547	46	46.8	1227	44	87.5	929	38	109.6
571	32	17.4	970	41	39.4	1281	42	63.5	933	40	40.4
630	34	23.5	1617	42	73.8	1263	44	67.2	802	38	66.3
454	29	24.2	361	29	42.5	1186	41	91.7	1170	42	54.1
1863	45	13.4	765	36	35.0	1163	40	120.3	785	38	80.3
1659	46	26.9	1709	44	47.4	1494	42	81.5	582	34	124.2
973	38	24.1	1275	45	51.4	1313	40	71.8			
1973	46	29.1									
1674	45	32.7									
Mean 1123	38	24.3	1055	39	49.1	1190	42	75.0	896	38	85.9
2xSE 260	3	2.2	235	3	6.6	72	1	8.7	203	3	26.6

Table B2. Comparative standard (S) and resting routine (RR), mass-independent 0, consumption rates (MO,, mg $O_2 \cdot kg^{-2/3} \cdot h^{-1}$) for several freshwater fishes at various temperatures (^{o}C).

Species	Temperature	MO$_2$		Reference
Carp	10	7.95	(S)	Beamish 1964
"	20	22.45	(S)	" "
Goldfish	10	7.34	(S)	Beamish & Mookherjii 1964
"	12	x = 29.02	(S)	" " "
''	21	x = 44.46	(S)	" " "
N. squawfish	9	24.30	(S)	(present study)
" "	15	49.10	(S)	" "
" "	18	75.00	(S)	" "
" "	21	85.90	(S)	" "
Rainbow trout	10	x = 29.34	(S)	Dickson & Kramer 1971
" "	15	x = 41.90	(S)	" " "
" "	15	52.39	(S)	Rao 1968
" "	20	x = 54.30	(S)	Dickson & Kramer 1971
Walleye	15	26.47	(S)	Tarby 1981
"	20	39.98	(S)	" "
Sac. squawfish	10	32.67	(RR)	Cech et al. 1990
" "	15	66.83	(RR)	" " " "
" "	20	73.99	(RR)	" " " "
Rainbow trout	10	57.22	(RR)	" " " "

Table B2. (continued)

Rainbow trout	20	97.46	(RR)	" " " "
Sac. blackfish	10	34.61	(RR)	Cech et al. 1979
" "	15	68.11	(RR)	" " " "
" "	20	95.32	(RR)	" " " "